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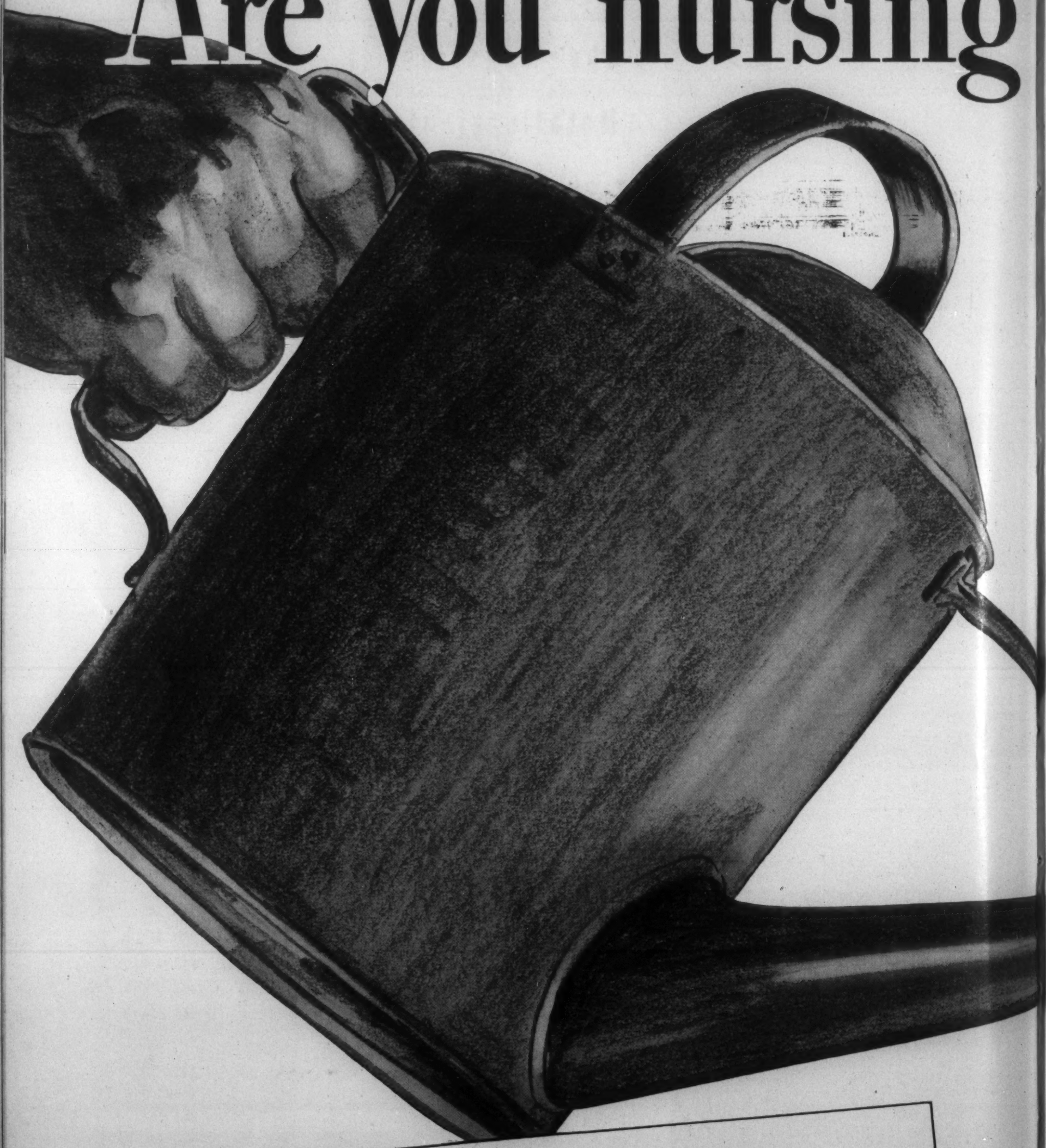


U·S·S CARILLOY

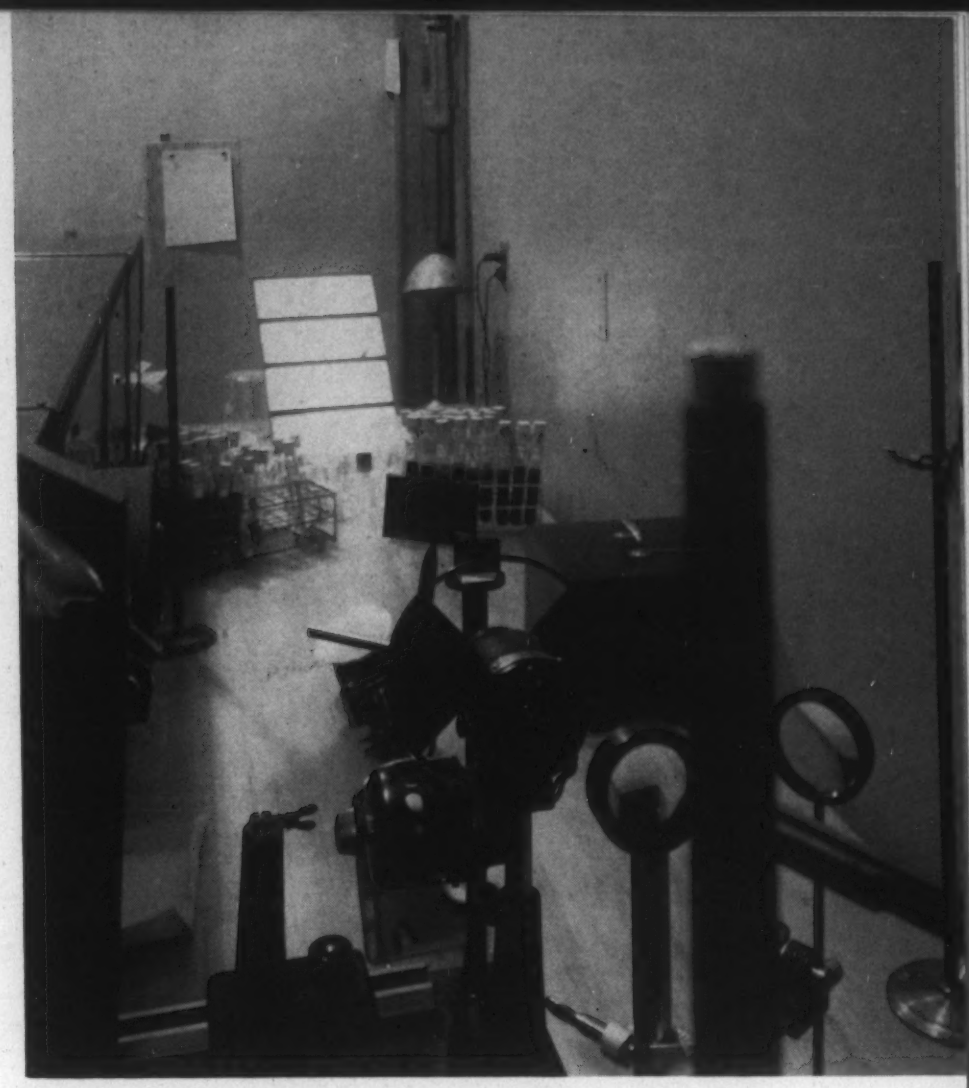
dependable ALLOY STEELS

Spectrographic Analysis

AT A LARGE TECHNICAL LABORATORY

by Abraham Mankowich

Associate Chemical Engineer,
Newport, R. I.



The Arc and Spark Stand from the Operator's Position at the Head of the Spectrograph. Note the auxiliary focusing system of lens, mirror and screen upon which are obtained enlarged images of the electrode tips. In the background are placed some of the synthetic standards.

The industrial position of spectrographic analysis as a practical tool for the engineering control of materials, by producer or consumer, has been indicated by our many articles on this subject. This contribution describes the successful application of a simple, easily standardized installation to a wide variety of ferrous and non-ferrous metallurgical products. Few plants may handle the large assortment of metals and alloys with which the author of this article must work, but practically all can find something in his description applicable to their own work. --The Editors.

THE ANALYTICAL SECTION of the laboratories with which the writer is connected inspects a wide variety of materials purchased to specification. Included among these materials are steels, brasses, bronzes, aluminum alloys, copper-nickel alloys, copper, pig lead, pig tin, spelter, silver solders, lead-tin solders, low-melting solders, brazing compounds, metal powders, explosives, oils, greases, foundry sands, carburizing compounds, gasolines, fuel oils, soldering fluxes, solvents, coal, coke, chemicals, electroplating salts and metals, rubber, leather, paper, gases, and miscellaneous other substances. The volume and the variety of work handled make it imperative that the analytical methods be rapid, as well as technically accurate.

Obviously, therefore, analyses of certain of the above materials have until recently presented serious problems. For example, the determination of antimony, tin, zinc, iron, bismuth, nickel, silver and copper in a 99.9 per cent pig lead is almost beyond the scope of a routine laboratory. Likewise, a cadmium determination in spelter is so long and laborious as to upset the routine of a laboratory such as ours. The necessity for analyses of chemicals of reagent grade, including barium nitrate, strontium nitrate and sodium nitrate, which are practically research projects, crystallized the feeling that some new tool was needed to supplement the ordinary chemical methods. The answer to this problem appeared to be the spectrograph.

Apparatus

Accordingly, a large Littrow-type spectrograph was purchased. Its wave-length range is 2100A to 8000A, with a linear dispersion of 1.5A per millimeter at 2200A and 36A per millimeter at 6300A, using a quartz optical system. The spectrum is photographed on a 2-in. by 10-in. plate. The illuminating system consists of an arc and spark stand, a plano-convex spherical lens and a rotating sector disc with adjustable aperture. The arc and spark stand supports the electrodes for the D. C. arc and the high tension spark. A variable rheostat is provided for use with a 110 volt, D. C. arc. A spark generator, consisting of a 0.45 kva step-up transformer, delivers 15,000 volts from a 110 volt, A.C. supply. A 0.005 microfarad condenser produces a condensed spark, while a variable self-induction coil (0 to 20 microhenries) eliminates air lines from the spark spectrum. The laboratory was also provided with a densitometer for determining the density of spectral lines. The densitometer consists of a voltage regulator, illuminator (200 watt monoplane filament lamp), photo-electric cell and a galvanometer mounted on a Julius Suspension.

Before the development program was begun, a list was

Another View from the Arc and Spark Stand, Looking Down along the Instrument. Some graphite electrodes were arced for a few seconds during the exposure.

made of those analyses for which it was believed the spectrograph was particularly adapted in this laboratory. Among them were the following:

(a) Molybdenum in stainless steel (approximately 13% chromium), from 0 to 0.60 per cent.
(b) Molybdenum in S.A.E. 4340 types of nickel-chrome-molybdenum steel, from 0.25 to 0.50 per cent.
(c) Lead, iron, cadmium, aluminum and tin in 98.75 per cent zinc.
(d) Lead, iron, cadmium and aluminum in Grade A spelter.
(e) Silver, bismuth, zinc, copper, antimony, tin, arsenic, iron and nickel in 99.9 per cent pig lead.
(f) Aluminum in copper-nickel alloy (Monel type), with aluminum ranging to 0.5 per cent maximum.
(g) Metallic impurities, chiefly copper, iron and zinc, in aluminum metal powder; iron ranging to about 0.5 per cent maximum and copper to about 0.03 per cent maximum.
(h) Zinc and iron in phosphor bronze, with a copper content of approximately 95 per cent and a tin content of about 5 per cent; the iron content runs to 0.10 per cent maximum, and the zinc content to 0.02 per cent maximum.
(i) Antimony and iron in the 88-8-4 type of bronze, with iron 0.10 per cent maximum and antimony 0.25 per cent maximum.
(j) Antimony and iron in leaded bronze (lead 15% and tin 11%), with iron 0.10 per cent maximum and antimony 0.25 per cent maximum.
(k) Lead, antimony, copper, bismuth and iron in 99.75 per cent pig tin.
(l) Sodium, calcium, magnesium and iron in barium nitrate.
(m) Iron, sodium and calcium in strontium nitrate.
(n) Calcium and magnesium in sodium nitrate.

It will be noted that the above analyses may be divided into three classes, each of which presents difficulties in an analytical laboratory intended primarily for rapid, routine technical analyses. The three classes, and the analyses that may be placed in each are as follows:

I. Long and laborious analyses: (a), (b), parts of (c) and (d), (f), (g) and (h).
II. Chemical analyses that were long and laborious and gave results that were liable to be in error, except in experienced hands: (i) and (j).
III. Chemical analyses that were beyond the scope of a routine laboratory: (e), (k), (l), (m) and (n).

In addition to the above analyses, the use of the spectrograph was indicated for the determination of zirconium and columbium in steels; small amounts of iron (0.05% maximum) in brasses, and for the analysis of ammonium perchlorate, etc.

Preliminary Work

The development of spectrographic methods for the aforementioned materials was begun with a serious lack of standard samples. There was on hand just one set of analyzed samples of nickel-chrome-molybdenum steel, with molybdenum ranging from 0.12 to 1.10 per cent. Attempts to obtain analyzed samples of the other metals and metallic alloys required met with failure. However, work was started on the nickel-chrome-molybdenum steels, using the 1/4 in. square standard electrodes, 2 in. long. An internal control method was developed, with high tension spark excitation of 15,000 volts. The molybdenum line at 2816.15A was used in conjunction with the iron line at 2813.29A. A working curve was drawn up in which the difference in densities of the molybdenum and iron spectral lines was plotted against the log of Mo concentration. The density for each line was taken as the log of its opacity. The details of this method will not be described, because soon after its completion it became evident that it would not be satisfactory in our laboratory, nor would any method requiring machined electrodes of the substance to be analyzed.

It was found that the added demands for preparing spectrographic electrodes on the laboratory machine shop, already running at capacity producing physical test specimens and chips for analysis, would detract from the usefulness of the spectrograph. This disadvantage, as well as the inability to obtain standard analyzed samples of the other required metals and alloys, with impurities varying over desired ranges, led to the adoption of solution methods using graphite electrodes. The use of solutions obviates the necessity of having a set of standard analyzed samples for every substance to be tested spectrographically.

Synthetic standard solutions may be prepared from chemicals found in every laboratory. Work once under way, it was surprising how many standards were easily prepared from the chemicals on hand. The only additional substances required for our purposes were spectrographic zinc and lead for use as the base materials in making the standards for the zinc and lead analyses. An analysis of our ammonium perchlorate for sodium, magnesium and calcium contents was also required; this was done by the U. S. Bureau of Standards.

Spectrographic Details

A feature of the methods developed at our laboratories is that all of the materials enumerated in a previous paragraph can be analyzed by using practically the same spectroscopic set-up. The advantages of such a system in a spectrographic laboratory that must handle a wide variety of work in a routine manner are obvious. All analyses are performed with the spectrograph adjusted to cover the ultra-violet range, 2400A to 3500A, using a quartz optical

system. The spectrum is photographed on 2-in. by 10-in. plates. All quantitative work is done with either No. 33 or Process plates as will be indicated later. A high contrast developer, formula "D-19," is used; developing time is 5 min. for Process plates and 2½ min. for No. 33 plates. A 10-sec. water rinse is followed by fixing in the "F-5" acid-hardening-fixing bath for 5 min. Developing and fixing solution temperatures are kept at 65 to 68 deg. F. Plates are given a final wash in water for 15 min.

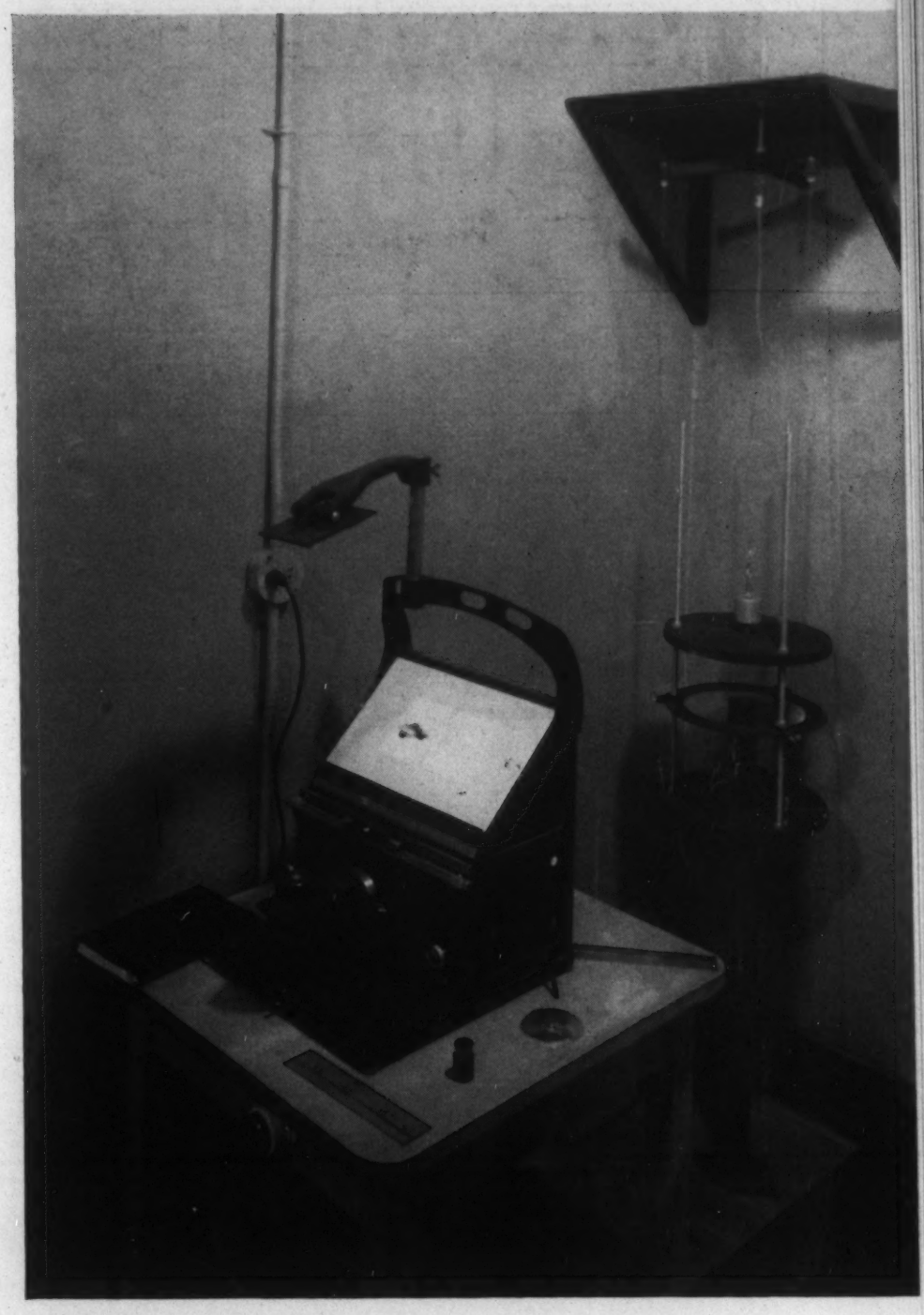
Excitation for all materials is the 110 volt, D.C. arc; and in every case, the arc is adjusted for a current of approximately 8 amps., with a 50-volt drop across the graphite electrodes. Two minute exposures are given for all materials. The graphite electrodes are 5/16 in. in diameter and 2 in. long. The lower, positive electrode, is recessed at one end; the dimensions of this recess are 0.227 in. in diameter by 0.160 in. deep, or 0.227 in. in diameter by 0.230 in. deep, depending on the size of the sample to be vaporized. The upper (negative) electrode is beveled into the shape of a very blunt chisel, and is placed in the upper electrode holder so that its edge is perpendicular to the axis of the spectrograph. The electrodes are burned in the 8-amp. arc for 30 sec. and cooled, before the solution is placed in the recessed anode.

This treatment renders the anode more porous and makes it (the 0.230-in. deep one) capable of absorbing as much as 0.2 c.c. of the solution to be analyzed. The solution, which is placed in the anode by a capillary pipette, varies from 0.07 c.c. to 0.20 c.c., depending on the particular material that is being analyzed. The size of the sample depends on the concentration of the substance being analyzed and on the substance itself. The electrodes are dried for 30 min. at 110 deg. C. A slit width of 40 microns is used for all quantitative work. All spectra are taken to give lines that are 3.3 mm. high. The rotating sector disc is adjusted to that opening which has been found to give optimum conditions in the case of each material.

The size of the sample to be used and the corresponding rotary disc setting for every material were determined as follows: The concentration of the substance in question having been determined (as well as the most convenient method of putting it into solution), a series of synthetic standard solutions of this concentration would be prepared containing the impurities in amounts to cover the desired ranges. Several series of spectra of these synthetic standards would then be made using the rotary sector openings and sample sizes that seemed to be indicated from inspection of the spectra. The sample size and rotary sector setting selected for future use were the ones producing a series of spectra in which the various selected impurity lines showed a definite weakening in density between successive standards.

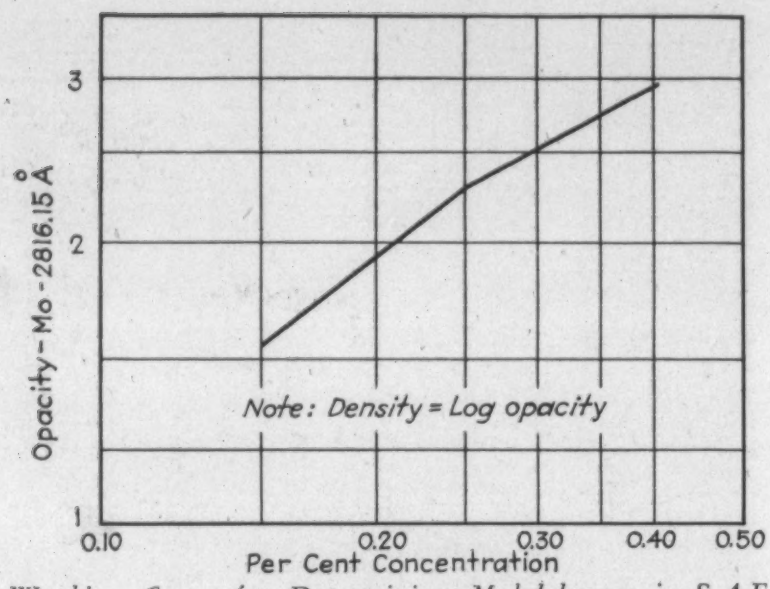
The actual analysis of a substance is then accomplished by comparing the spectrum of the unknown solution with the spectrum of one of the synthetic standards. The synthetic standard solution selected to produce the comparison spectrum is usually the one containing the maximum amounts of impurities specified; it may, however, be the standard containing the impurities in amounts ordinarily found in the substance.

It is to be noted that, in this laboratory, only one comparison spectra is photographed on the plate with the unknown. Two methods are used to make the final determinations of the values of the unknown impurities. In the first method, the plate containing the unknown and comparison spectra is compared with several standard plates containing the series of spectra of the standards. A match is quickly found for the comparison spectrum on the plate with the unknown and the spectrum from the same standard solution on one of the standard plates. The unknown spectrum is then estimated from the latter standard plate. With several standard plates, it is easy to find one that is comparable with the plate containing the unknown sample.



The Density Comparator with the Galvanometer Placed on a Julius Suspension.

The second method involves the use of a working curve of density of impurity line (log of opacity) as measured by the densitometer against log of the concentration of the impurity. This curve is based on values obtained from several standard plates. Then, if the density of the impurity line of the comparison spectrum falls on this curve, the value of the impurity line of the unknown may be read off directly from this curve. If the density of the impurity line in the comparison spectrum falls outside the curve, a parallel curve (line) is drawn through this point, and the value of the unknown read off this latter curve. The accuracy obtained with either method of evaluating the plates is considered the equal of the usual method described by Nitchie, requiring that all the standard spectra be photo-



Working Curve for Determining Molybdenum in S.A.E. 4340 Steel.

graphed on the same plate as the unknown. Either method results in an appreciable saving in time over the original Nitchie method; and, for a routine laboratory, gives satisfactory accuracy.

Standard Solutions and Solutions for Analysis

Synthetic standard solutions were prepared from materials that, with few exceptions, were available in the laboratory.

The standards for the determination of molybdenum in stainless steel (corrosion-resisting-steel) were prepared by adding definite quantities of standard molybdic acid solution to solutions of samples of the Bureau of Standards Stainless Steel No. 73, whose chromium content is 13.93 per cent and molybdenum content 0.005 per cent. The molybdic acid solution was made by dissolving 1 gram of 100 per cent MoO_3 in 5 c.c. concentrated NH_4OH, and diluting to 22.2 c.c. with water. Hence, 1 c.c. of this solution is equivalent to 0.03 grams molybdenum. Samples of the No. 73 steel were weighed out and 30 c.c. of 1-1 HCl added. The solutions were boiled, oxidized with 1-1 HNO_3 and cooled. Standard molybdenum solution was then added by a micropipette. All solutions were then diluted to 30 c.c. with water. The amount of molybdic acid was calculated so that the five standards varied in steps of 0.15 per cent Mo, the steel sample plus Mo amounting to 2 grams. This gave synthetic standard solutions with a concentration of 1 gram steel per 15 c.c. solution.

To analyze a sample of this type of steel, a solution is prepared by dissolving 2 grams in 30 c.c. of 1-1 HCl, boiling, oxidizing with 1-1 HNO_3, cooling and diluting to 30 c.c. with water. For analysis, a 0.2 c.c. sample of this solution is placed in a recessed graphite electrode, 0.230 in. deep.

To prepare the synthetic standard solutions for the determination of molybdenum in S. A. E. 4340 nickel-chrome-molydbenum steel, the Bureau of Standards Steel No. 32-b was used as a base. This steel analyzes as follows: 0.413 C, 1.21 Ni, 0.638 Cr and 0.005 per cent Mo. The molybdic acid solution used for the corrosion-resisting steel standards was also used in this case. These standards ran from 0.25 to 0.50 per cent Mo in steps of 0.08 per cent Mo.

The samples of the No. 32-b steel were treated with 25 c.c. of 1-1 HCl and 5 c.c. of 1-1 HNO_3; boiled; then the solutions were evaporated to about 20 c.c. volumes. They were then filtered, and washed with hot 1-1 HCl and water. Suitable amounts of molybdic acid solution were then added to the corresponding solutions; each solution was then diluted to 30 c.c. with water. The steel sample plus Mo in each case amounted to 2 grams. This gave standard solutions whose concentration was 1 gram steel per 15 c.c. To analyze a steel of this type, a 2-gram sample is treated as above in preparing the standards, with the exception of the addition of the molybdic acid solution. The analysis is performed on a 0.2 c.c. portion of this solution in a graphite electrode, 0.230 in. deep.

In preparing synthetic standard solutions for use in analyzing zinc, spectroscopically-pure zinc (99.9987%) was used as a base. Four standards of the following compositions were made up:

	No. 1, Per Cent	No. 2, Per Cent	No. 3, Per Cent	No. 4, Per Cent
Iron	0.04	0.03	0.02	0.01
Lead	0.50	0.36	0.23	0.10
Cadmium	0.24	0.18	0.12	0.06
Zinc	Remainder	Remainder	Remainder	Remainder

These solutions were prepared from suitable weights of the following: Zinc, spectroscopic; lead, spectroscopic; iron, reagent wire (99.8%); and Cd $(OH)_2$, C.P.

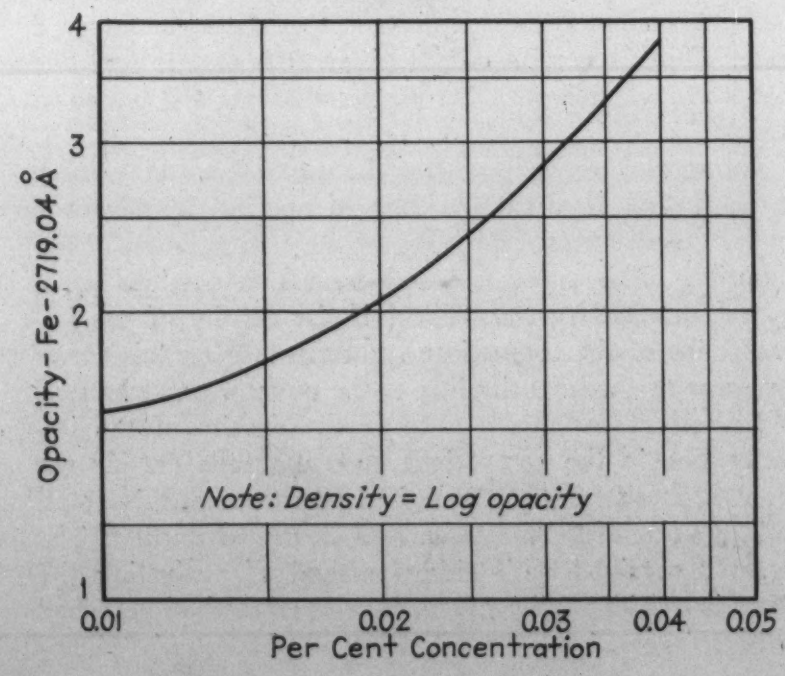
The materials comprising each standard (10 grams) were treated with 15 c.c. concentrated HCl. When action stopped, 15 c.c. concentrated HNO_3 was added. When solution is complete, dilute to 30 c.c. with concentrated HCl. This gives standards whose concentration is 1 gram metal per 3 c.c. To analyze a sample of zinc, a 10 gram sample is treated as above. The analysis is performed on a 0.07 c.c. sample, using a graphite electrode with a 0.160-in. deep recess.

For making standards to be used for Grade A spelter, four standards of the following composition were similarly made up:

	No. 11, Per Cent	No. 12, Per Cent	No. 13, Per Cent	No. 14, Per Cent
Iron	0.03	0.02	0.02	0.01
Lead	0.07	0.05	0.03	0.01
Cadmium	0.07	0.05	0.03	0.01
Zinc	Remainder	Remainder	Remainder	Remainder

The materials comprising the above four standards were put into solution in exactly the same manner as the standards for the Grade A zinc. The metal concentration of the standards was 1 gram per 3 c.c. as before. To analyze Grade A spelter, a 10-gram sample is treated as the standards were. The analysis is performed on a 0.10

Working Curve for Determining Iron in Zinc. Specification 47-Z-6a.



c.c. sample, using a graphite electrode with 0.160 in. deep recess.

For the spectroscopic determination of the impurities in 99.9 per cent minimum lead, two sets of standards were made up. One set (L-series) contains the silver, bismuth, zinc and copper impurities, the other set (S-series) contains the tin, antimony, iron and nickel impurities. The composition of the L-series of standards is:

	L-1, Per Cent	L-2, Per Cent	L-3, Per Cent
Silver	0.005	0.003	0.001
Bismuth	0.005	0.003	0.001
Zinc	0.002	0.001	0.0005
Copper	0.060	0.030	0.010
Lead	Remainder	Remainder	Remainder

For use in making the above standards, impurity solutions were made up:

Bismuth 0.200 grams $Bi(NO_3)_3.5H_2O$ in 25 c.c. water.
Silver 0.200 grams $AgNO_3$ in 100 c.c. water.
Zinc 0.100 grams ZnO dissolved in HNO_3 and diluted to 100 c.c. with water.

The L-series of standards was prepared from suitable amounts of spectroscopic lead, these solutions, and c.p. copper nitrate. These materials (4 grams per standard) were treated with 6 c.c. concentrated HNO_3 plus 16 c.c. water; cooled, and diluted to 32 c.c. with water.

Hence, the metal concentration was 1 gram per 8 c.c. of solution. To analyze a sample of high purity lead for the L-series of impurities, 4 grams is treated as just outlined, and a 0.1 c.c. portion is taken for analysis in a graphite electrode with a recess 0.160 in. deep.

The composition of the S-series of standards is as follows:

	S-1, Per Cent	S-2, Per Cent	S-3, Per Cent
Antimony	0.01	0.005	0.001
Tin	0.003	0.002	0.001
Iron	0.005	0.003	0.001
Nickel	0.008	0.004	0.001
Lead	Remainder	Remainder	Remainder

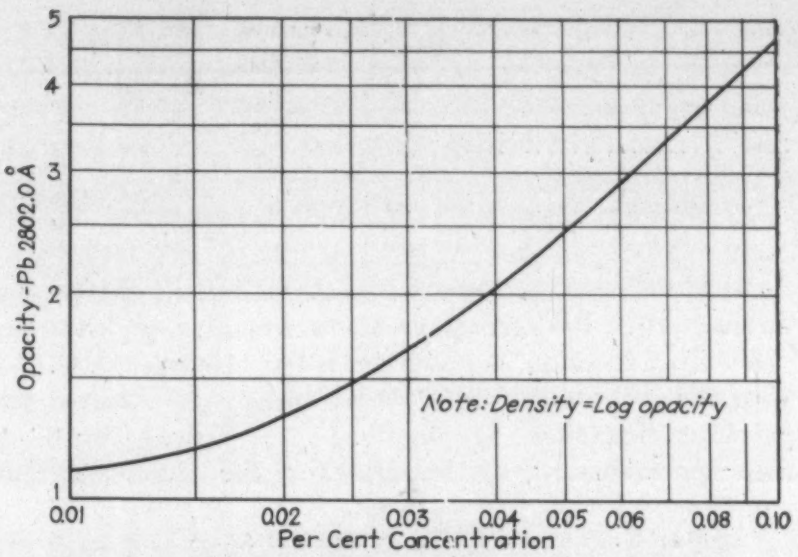
Impurity solutions for making the S-series standards were prepared as follows:

Iron 0.100 gram iron reagent wire was dissolved in HNO_3 and diluted to 100 c.c. with water.
Nickel 0.100 gram C.P. $Ni(NO_3)_2.6H_2O$ in 27 cc. water.
Antimony 0.100 gram antimony powder dissolved in HCl and HNO_3, and diluted to 100 c.c. with water.
Tin 0.100 gram reagent tin dissolved in HCl and HNO_3, and diluted to 100 c.c.

The S-series of standards were then prepared from suitable amounts of spectroscopic lead and these solutions.

These materials were treated similarly to the L-series of standards. This resulted in the same metal concentration of 1 gram per 8 c.c. A sample of lead for analysis for the S-series of impurities is also treated as for the L-series; however, a 0.2 c.c. portion is taken for analysis in a graphite electrode with a recess that is 0.230 in. deep.

Standards for use in the determination of aluminum in copper-nickel alloy (Monel metal), were prepared as follows:



Working Curve for Determining Lead in Pig Tin.

It was decided that the synthetic standard copper-nickel alloy would be composed of:

	Per Cent
Copper	29.0
Nickel	68.5
Iron	1.3
Manganese	0.9

This is the approximate composition of the substance as usually received. Hence, on a basis of 25 grams of metal, there was weighed out:

	Grams
Copper, 99.9% grade	7.25
$Ni(NO_3)_2.6H_2O$—C.P.	84.8
Iron wire, reagent grade	0.324
$Mn(CH_3CO_2)_2.4H_2O$—C.P.	1.00

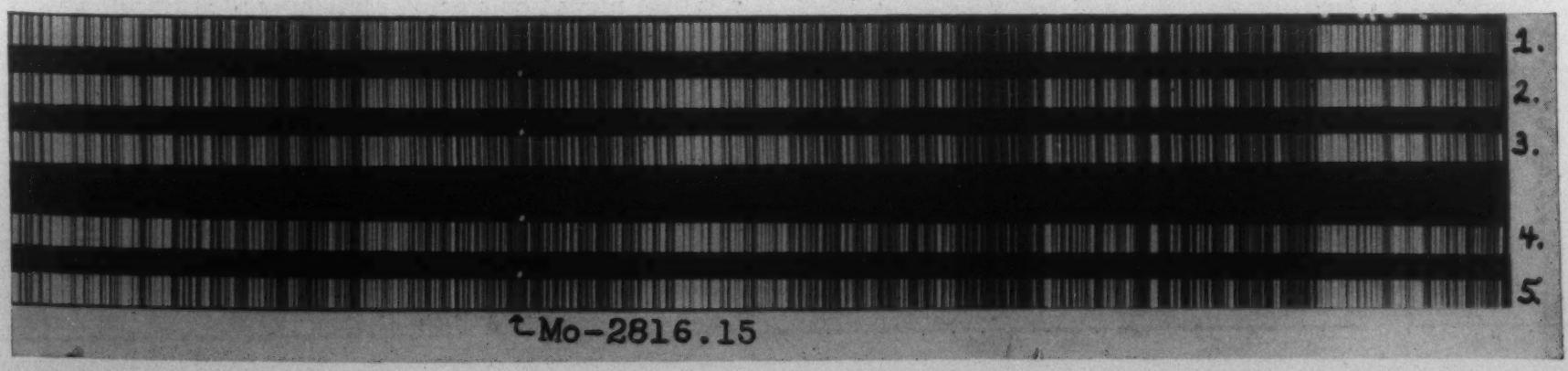
These materials were dissolved in 65 c.c. concentrated HNO_3, and then diluted to 150 c.c. with H_2O. To 25 c.c. aliquots of the 150 c.c. solution, there was then added suitable amounts of standard aluminum solution to give 0.05, 0.10, 0.25 and 0.50 per cent Al.

The 25 c.c. aliquots, after receiving their respective amounts of aluminum solution as above, were diluted to 33.3 c.c. This resulted in standards with a metal concentration of 1 gram metal per 8 c.c. solution. The aluminum solution was prepared by dissolving a 1 gram sample of Bureau of Standards aluminum (99.885% Al) in 15 c.c. aqua regia and then diluting to 100 c.c. with water. A sample of copper-nickel alloy for analysis is treated as follows: 2 grams are dissolved in 16 c.c. of 1-1 HNO_3, cooled, and diluted to 16 c.c. with water. This approximates the acid content of the standards. A 0.1 c.c. portion is used for analysis.

Summary of Spectrographic Details

In the following, a summary of the spectrographic details that are used with the materials and standards just described is given:

Spectrograms of Standard Steels—S.A.E. 4130 Type. No. 1—0.005% Mo; No. 2—0.25% Mo; No. 3—0.33% Mo; No. 4—0.40% Mo and No. 5—0.50% Mo.



	Sample Size, c.c.	Depth of Recess In Anode, in.	Rotary Sector Opening, Per Cent	Plate
Corrosion-Resisting steel	0.20	0.230	25.0	Process
S. A. E. 4340 steel.....	0.20	0.230	50.0	Process
Zinc	0.07	0.160	12.5	No. 33
Zinc, Gr. A	0.10	0.160	25.0	No. 33
Lead, 99.9% minimum.				
"L"-impurities	0.10	0.160	12.5	Process
"S"-impurities	0.20	0.230	100.0	Process
Copper-nickel alloy	0.10	0.160	100.0	No. 33

In addition, all exposures are 2 min.; all slit widths are 40 microns. Processing of plates has already been described. Excitation in every case is the 110 volt, D. C. arc, with the arc adjusted to 8 amps. and 50 volts across the graphite electrodes, as described previously. The lines used for evaluating the impurities in the above materials are:

Steels	Mo at 2816.15 A
Zincs	Cd at 3261.05 A
	Pb at 2873.32 A
	Fe at 2719.04 A
Leads	Sb at 2598.08 A
	Sn at 2863.32 A
	Fe at 2719.04 A
	Ni at 3002.49 A and 3003.63 A
	Ag at 3280.67 A and 3382.88 A
	Bi at 3067.73 A
	Zn at 3345.6 A and 3345.9 A
	Cu at 3247.55 A and 3273.97 A
Copper-nickel alloy.....	Al at 2660.3 A

Special Methods

In the preceding, the writer has given details for the preparation of synthetic standards and methods of spectrographic analysis for several materials. These are typical of several dozen methods that have been developed for metallurgical substances. However, our laboratories also examine high purity chemicals, including sodium nitrate, barium nitrate and strontium nitrate, and others. In attempting to work up spectrochemical procedures for these salts, it was found impossible to make satisfactory progress using methods similar to the ones for metallurgical alloys. For example, in the determination of calcium and sodium in barium nitrate, graphite electrodes and the ultra-violet spectral range proved unsatisfactory. The graphite electrodes contained sufficient calcium to make the determination of this element impossible. The increased blackness of the background in the region of the sodium lines at 3302.34 A and 3302.94 A also made it impossible to detect sodium with graphite electrodes. The method to be described here was finally developed for the analysis of barium nitrate. It is typical of the methods of analysis of many of our chemicals.

Instead of graphite, copper is used for the electrode material. The copper electrodes are 0.444 in. in diameter by 2 in. long. The anode has drilled in its upper end a recess, 0.358 in. in diameter by 0.190 in. deep. The cathode is given a very blunt chisel-edge. The synthetic standards are in the form of dry salts containing varying amounts of impurities. The base material for the barium nitrate standards is our C. P. barium nitrate, which contains a trace of sodium (negligible) and 0.008 per cent of calcium salts as CaO. In preparing the synthetic standards, standard calcium and sodium impurity solutions were first made as follows:

Calcium: 1 gram C.P. $CaCO_3$ is dissolved in a small amount of HNO_3; boil thoroughly; and dilute to 50 c.c. with water.

Sodium: 1 gram of C.P. $NaNO_3$ is dissolved in water and diluted to 20 c.c.

Suitable amounts of C.P. barium nitrate are then placed in 250 c.c. beakers and the proper amounts of standard calcium and sodium solutions, given below, are added from a burette. The mixtures are well stirred, and then placed in a 100 deg. C. oven until dry. When dry, the salts are ground in a mortar, and well mixed, resulting in dry, synthetic chemicals with impurities covering the desired ranges. For our standards, the following mixtures were adopted:

	Standard No. 0, Per Cent	Standard No. 1, Per Cent	Standard No. 2, Per Cent
NaO	trace	0.093	0.15
CaO	0.008	0.15	0.30

In analyzing a sample of barium nitrate, a 0.5000 gram sample is placed in the recess of the copper anode. Excitation is by the 110 volt, D.C. arc, with the arc adjusted to give a current of 3.5 amperes. A No. 144-B plate is used. The slit is reduced to 20 microns. The exposure is reduced to 1.5 min.; and the rotary sector is set to transmit 12.5 per cent of the light. The plate is developed 2.5 min., rinsed and fixed 5 min., using the solutions previously described. The spectrograph is adjusted to photograph the spectral region between 3680 A and 6500 A, using quartz optics. On the plate with the sample to be analyzed is placed the spectrum from one of the above standards. The lines used for evaluating the calcium and sodium are:

Calcium: The pair of lines at 3933.67 A and 3968.47 A
Sodium: The pair of lines at 5889.97 A and 5895.93 A

The spectrographic methods described have been tested for accuracy and precision and also compared with routine chemical methods. Repeated spectrographic analyses for molybdenum were made on Bureau of Standards Steel No. 111, the molybdenum content of which is 0.215 per cent. These results were then compared with the routine chemical analysis on the same steel. Results were as follows:

Analysis No.	By Spectrographic Analysis, Per Cent	Accuracy, Per Cent
1	0.195	— 9.3
2	0.183	—14.9
3	0.225	+ 4.7
4	0.200	— 7.0
5	0.230	+ 7.0
6	0.212	— 1.4
7	0.185	—14.0

Averaging the above table gives:

		Per Cent
Spectrographic Analysis.	Percentage Accuracy	8.3
	Percentage Deviation of Mean	2.8
Chemical Analysis	Molybdenum	0.24
	Percentage Accuracy	11.6

These spectrographic analyses were made by one of the methods outlined; namely, the spectrum of the Bureau of Standards Steel No. 111 was photographed on a plate with one of the S.A.E. 4340 synthetic standards. A special standard was prepared for this purpose, containing 0.15 per cent molybdenum. Then, opacities of the molybdenum lines at 2816.15 A were determined for both spectra, using the densitometer. Opacity was considered equal to

$$\frac{\text{clear plate reading} - \text{zero reading}}{\text{molybdenum line reading} - \text{zero reading}}$$

The opacity of the 0.15 per cent molybdenum standard was then plotted on a graph containing the curve of opacity versus concentration for our S. A. E. 4340 synthetic standards, using double log paper. A line was drawn parallel to this curve through the 0.15 per cent point, and the value of the molybdenum content of Bureau of Standards Steel No. 111 was read off this curve.

Frequently, the accuracy of a method has been tested as in the following case of the determination of antimony in bearing bronze:

		Per Cent
Spectrographic Analysis of Ingot:	Sb	0.10
Antimony powder added to heat equivalent to		0.12
Spectrographic Analysis of Casting:	Sb	0.24

It is the belief at this laboratory that our spectrographic methods give greater accuracy than many of the chemical methods which they have displaced. This is particularly true in molybdenum determinations in steel where it has been found that chemical determinations may easily be 50-75 per cent in error, if the analyst has relaxed his attention to detail in the least.

Conclusion

The writer has described in detail some methods used at a large, technical laboratory, for the spectrochemical analysis of a wide variety of products. Methods for the preparation of synthetic standards are indicated, and attention is drawn to the fact that many standards can be prepared from materials found in every laboratory. Reasons are given to demonstrate that the graphite electrode-solution methods are preferable in a busy laboratory that cannot wait for metallic electrodes to be machined from the substance to be analyzed.

Wanted: An International Committee on Nomenclature

by Albert Sauveur

Cambridge, Mass.

IT MUST BE APPARENT to American students of metallography that a schism has developed in their ranks which, if not promptly healed, will confuse and disconcert new adepts in this important field.

I have more especially in mind the differences of opinion held by certain groups as to the meanings which should be attached to the terms pearlite, sorbite, and troostite.

In 1910 a committee was organized by the International Association for the Testing of Materials to consider "the nomenclature of the microscopic substances and structures of steel and cast iron." This committee was composed of the following members: H. M. Howe (United States), chairman; F. Osmond (France), H. C. H. Carpenter (England), W. Campbell (United States), C. Benedicks (Sweden), F. Wüst (Germany), A. Stansfield (Canada), J. E. Stead (England), L. Guillet (France), E. Heyn (Germany), W. Rosenhain (England), and Albert Sauveur (United States), secretary.

In its report presented in 1912 the committee defined pearlite in the following terms: "The iron-carbon eutectoid consisting of alternate masses of ferrite and cementite. A conglomerate of about 6 parts of ferrite and 1 of cementite. When pure, contains about 0.90 per cent of carbon, 99.10 per cent of iron."

The definition implied that pearlite was that constituent, approximately eutectoid in composition and clearly lamellar in structure, resulting from the slow cooling of iron-carbon alloys through their thermal critical ranges. It was the product of the slow transformation of austenite of eutectoid composition. If austenite was not originally of eutectoid composition, then not until it had reached that composition through the rejection of ferrite or of cementite would pearlite form. All of which was in agreement with our understanding of the teaching of the equilibrium diagram.

This conception of the nature of pearlite was universally accepted and remained unchallenged for a quarter of a century.

In recent years, however, some writers have proposed to describe as pearlite all aggregates of ferrite and cementite, with the exception of martensite, resulting from the cooling of austenite to room temperature quite regardless of the carbon content and microstructure of these aggregates. In other words, they now propose to describe as pearlite those structures or constituents which in the past had been designated as troostite and sorbite.

To illustrate: steel containing some 0.40 per cent carbon cooled in air from its austenitic range, so generally considered as sorbitic, is described by them as consisting of pearlite, although that pearlite would contain but one half the normal amount of carbon present in the eutectoid and be very imperfectly lamellar, and that only in spots. Its ferrite lamellae would have to be some fourteen times thicker than its cementite lamellae.

In an attempt to show that pearlite is not necessarily of eutectoid composition, it is sometimes pointed out that iron-carbon alloys containing considerably less carbon or considerably more carbon than the eutectoid, possibly as little as 0.75 per cent or as much as 0.95 per cent, appear under microscopical examination to be wholly pearlitic. This I believe to be due chiefly to the difficulty of detecting the occurrence of small amounts of ferrite or of cementite and does not affect the soundness of the definition proposed by the committee.

To have certain authoritative writers refer to some microstructures of steel as consisting of pearlite while other no less authoritative writers describe them as sorbite or troostite should not be tolerated.

We should speak the same language, but it is not for any one of us, nor for any small group, nor even for any large group to decide what that language should be. It must be an universal language and not a Yankee dialect, unless indeed the Yankee dialect is adopted as the universal language. There is no room here for arbitrariness, sophistry, or provincialism.

So important a matter can only be decided by an international committee made up of outstanding metallurgists representing the various countries in which metallographic studies are actively pursued.

Editor's note—Comment is invited from those who have opinions on this topic.

Courtesy: United States Steel Corp. Research Laboratory

Metallurgist Making Creep Test Reading in Specially Designed Furnaces

THE MANUFACTURE OF

Cast Trunnion Bearing Metal

AND ITS MECHANICAL PROPERTIES

Part II

(Concluded from the May Issue)

by Joseph A. Duma

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MICROSTRUCTURE

SPECIMENS for microscopic examination were taken from the large ends of broken tensile bars. They were etched by swabbing with NH_4OH-H_2O_2, and their structure photographed at magnifications of 100 and 500 diameters.

Photomicrographs

The photomicrographs in Figs. 3 to 12 inclusive depict the structural characteristics of good and bad trunnion bearing metal. A study of the structures in relation to their physical properties (shown in Table V) discloses the following:

(a) The percent elongation parallels very closely the percent of alpha phase present in the structure; and, as expected, the tensile strength varies in the opposite direction.

(b) All other things remaining equal, the smaller grain structure has the greater ductility and vice versa.

(c) Apparently neither the size, nor the form, nor the density of the Fe-Zn crystals exerts any considerable influence on the mechanical properties. Good and bad manganese bronze, and good and bad trunnion bearing metal contain them.

(d) Fine alpha needles are associated with high strength combined with high elongation.

(e) The structures whose physical properties meet specification requirements are homogeneous beta containing very little, if any, alpha material.

The probable microstructure for various combinations of tensile strength and elongation may be forecast as follows:

Physical Combinations	Microconstituents
Sufficient ductility* but insufficient strength. (Figs. 4 and 5).	Numerous and coarse alpha reeds in a beta matrix.
Sufficient tensile strength but insufficient ductility. (Figs. 9 and 10).	Little, if any, alpha material; or coarse,** structureless beta.
Insufficient tensile strength and insufficient ductility (Fig. 10).	Long acicular shafts of alpha in beta; or alpha grains enmeshed in a mottled network of brittle material.
Sufficient tensile strength and sufficient ductility. (Figs. 7 and 8).	Fine alpha reeds in comparatively small grains of beta; or homogeneous beta also of small grain size.

* Insufficient ductility—less than 15.0%.
Insufficient tensile strength—less than 100,000 lbs. per sq. in.
* * Coarse grain—greater than 1½ in. in any direction under 100X.

HEAT TREATMENT

IT WAS believed that extremely hard and brittle trunnion compositions might be made ductile, and conversely, soft and weak ones strengthened, by heat treatment. A search

Table V—Physical Properties of the Metals Shown in Figs. 3 to 12

Heat No.	Chemical Composition, Per Cent: Cu	Zn	Fe	Mn	Al	Shown in Fig.
333E	73.31	16.75	3.05	3.75	3.14	3
5	....	....	...	...	...	4
334	71.37	18.58	2.01	3.51	4.53	5
397	68.51	21.55	2.10	3.34	4.50	6
440	67.48	22.26	2.27	2.64	5.34	7
362	65.78	23.32	2.49	3.61	4.80	8
325	66.93	23.11	1.92	4.29	3.51	9
390	....	....	...	...	...	10
51	71.70	14.91	3.02	4.32	6.05	11
333A	73.31	16.75	3.05	3.75	3.14	12

Heat No.	Physical Properties: Tensile Strength, lbs. per sq. in.	Yield Point, lbs. per sq. in.	Elongation, per cent	Reduction Area, per cent	Brinell Numeral
333E	73,250	31,250	44.5	43.50	128
5	79,450	35,000	31.5	30.28	138
334	85,750	46,000	21.5	22.35	167
397	101,500	60,000	18.0	20.50	192
440	104,500	63,000	15.0	17.00	196
362	115,500	82,250	17.0	19.89	223
325	120,000	78,750	10.0	13.38	223
390	112,500	83,750	13.5	16.50	223
51	92,000	54,150	5.0	7.00	202
333A	57,000	30,500	15.0	22.19	116

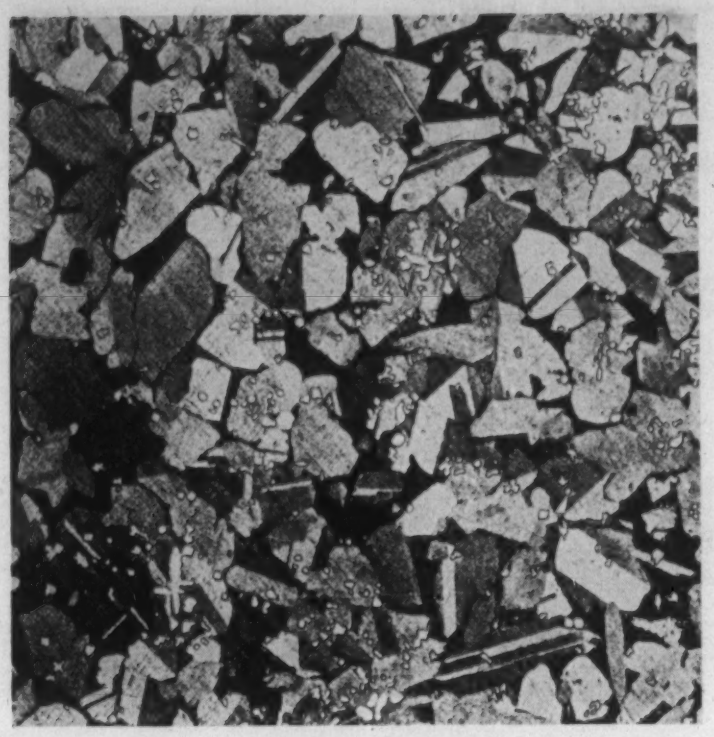


Fig. 3. Photomicrograph of Heat No. 333E Shows Fairly Fine, Twinned Alpha Grains Together with Some Beta. 100 X.

Fig. 3A. Same as Fig. 3 but at 500 X.

Fig. 3B. Same as Fig. 3 but Unetched, Showing Fe-Zn Crystals. 100 X.

Fig. 4A. Same as Fig. 4 but at 500 X.

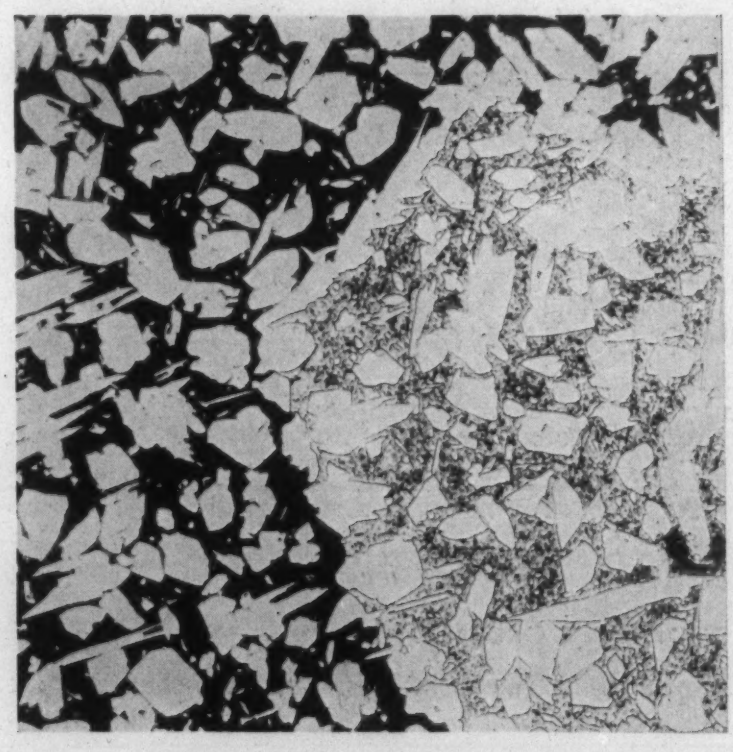
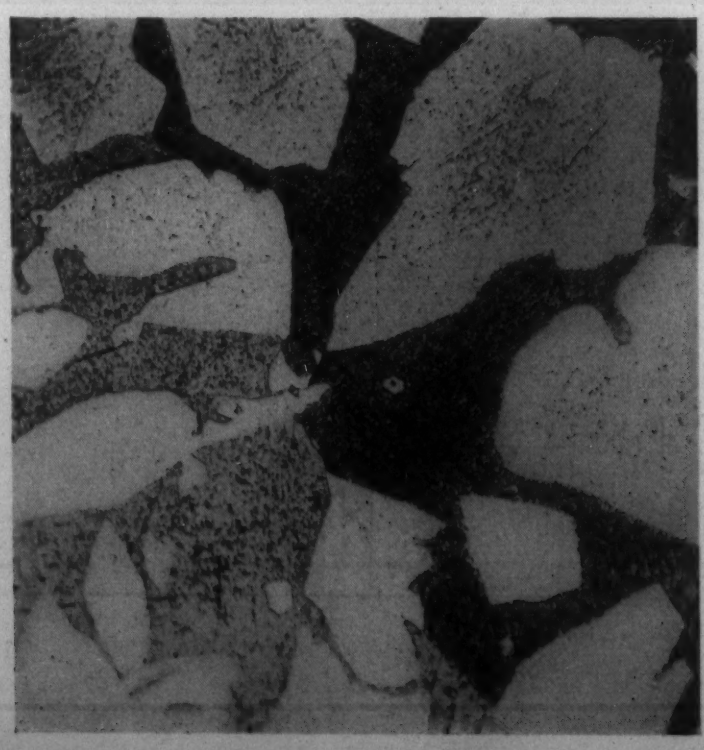
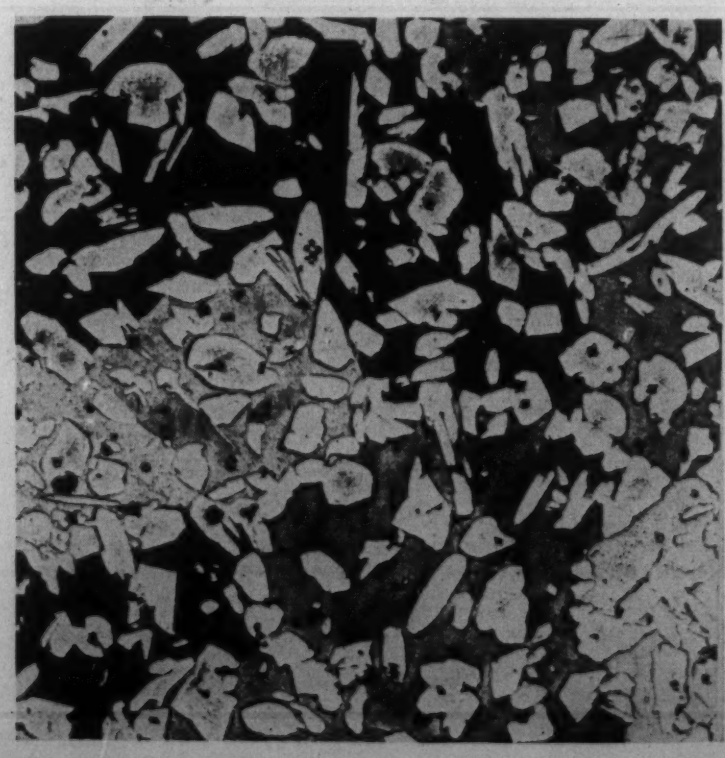


Fig. 4. Photomicrograph of Heat No. 5 Shows Small Fe-Zn Crystals wth Dark Centers, Scattered in Alpha (White Grainlets) and in Beta (Dark Ground Mass) 100 X.

Fig. 5. Photomicrograph of Heat No. 334 Shows Alpha in a Matrix of Beta. 100 X.





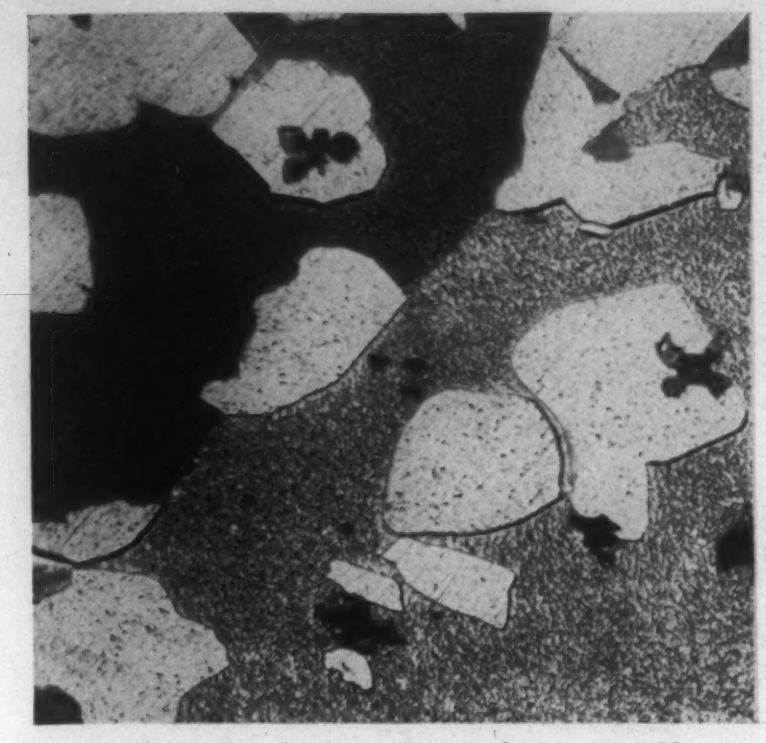


Fig. 5A. Same as Fig. 5 but at 500 X.

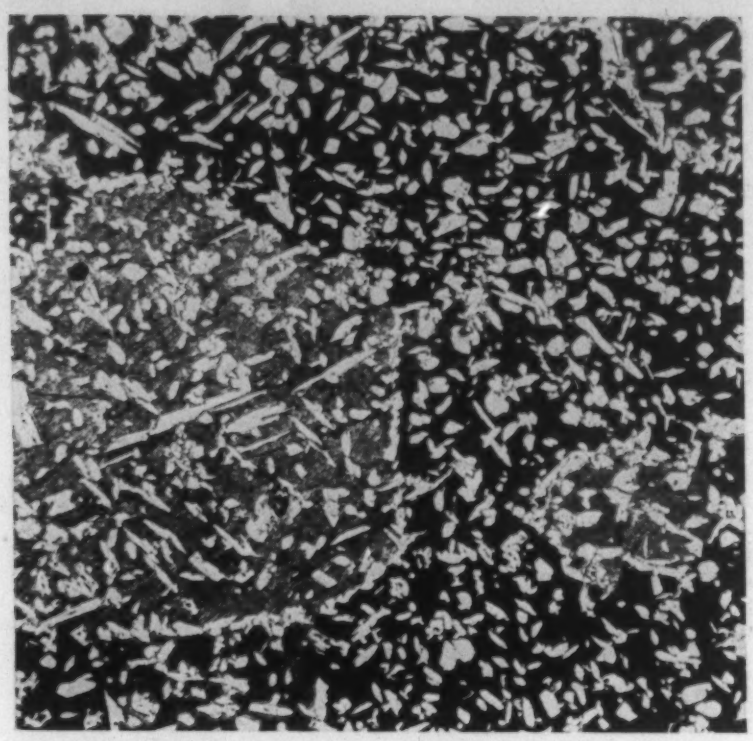


Fig. 6. Photomicrograph of Heat No. 397 is Made Up of Small Reeds of Alpha Lying within Grains of Beta. 100 X.

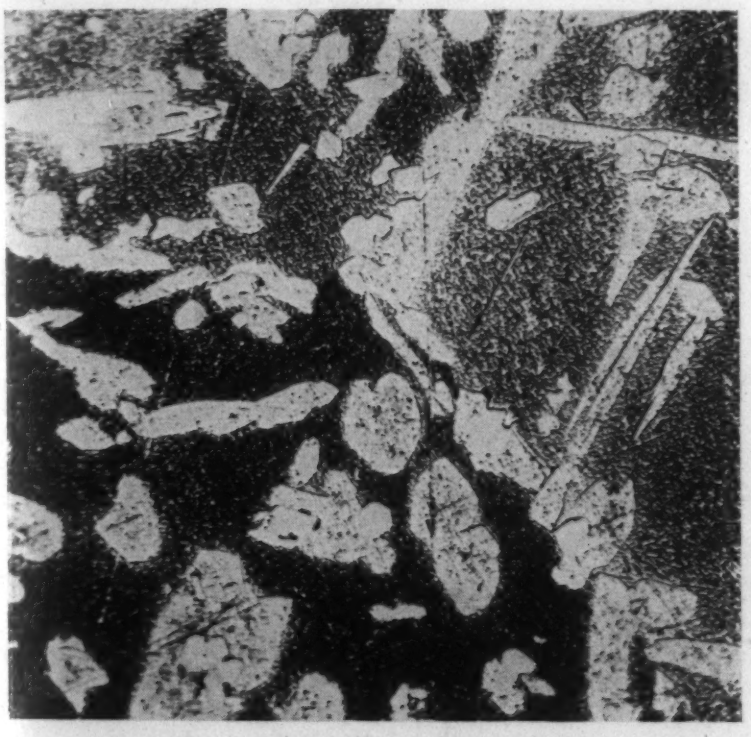


Fig. 6A. Same as Fig. 6 but at 500 X.

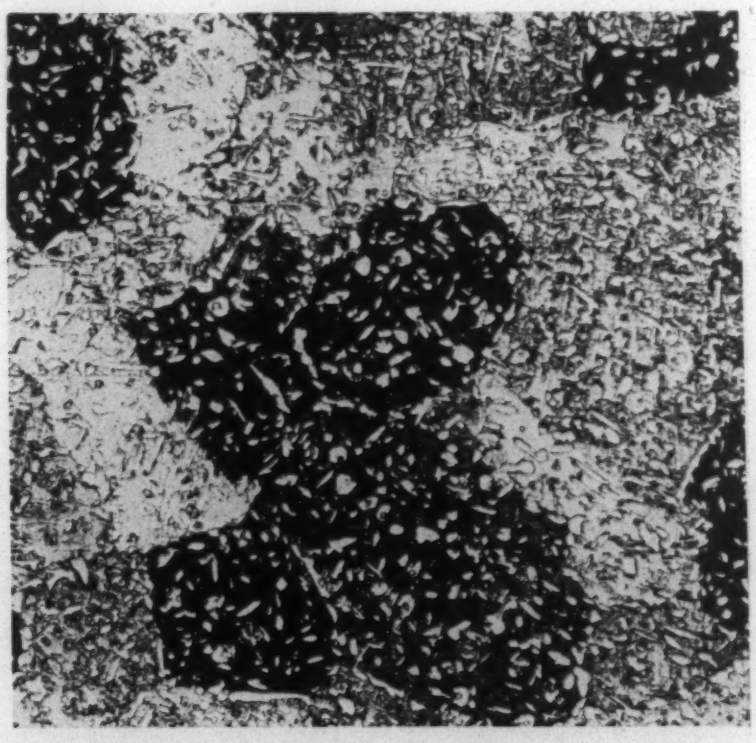
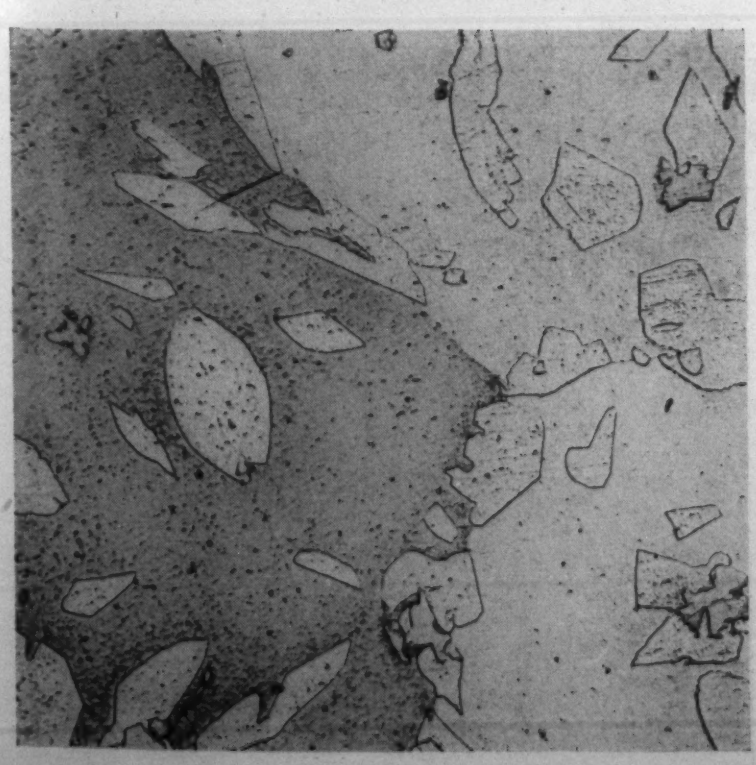
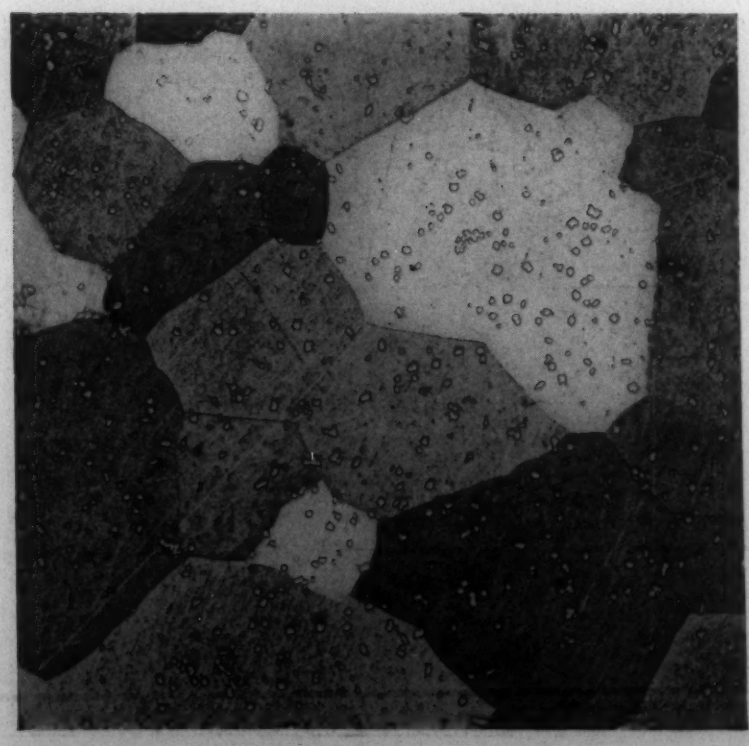


Fig. 7. Photomicrograph of Heat No. 440 Shows Fine Grainlets of Alpha in Beta. 100 X. Compare the size and the number of the above alpha and beta grains with those in Fig. 4.

Fig. 8. Photomicrograph of Heat No. 362 Shows Beta Containing Tiny Crystals of Fe-Zn Compound. 100 X.

Fig. 7A. Same as Fig. 7 but at 500 X.





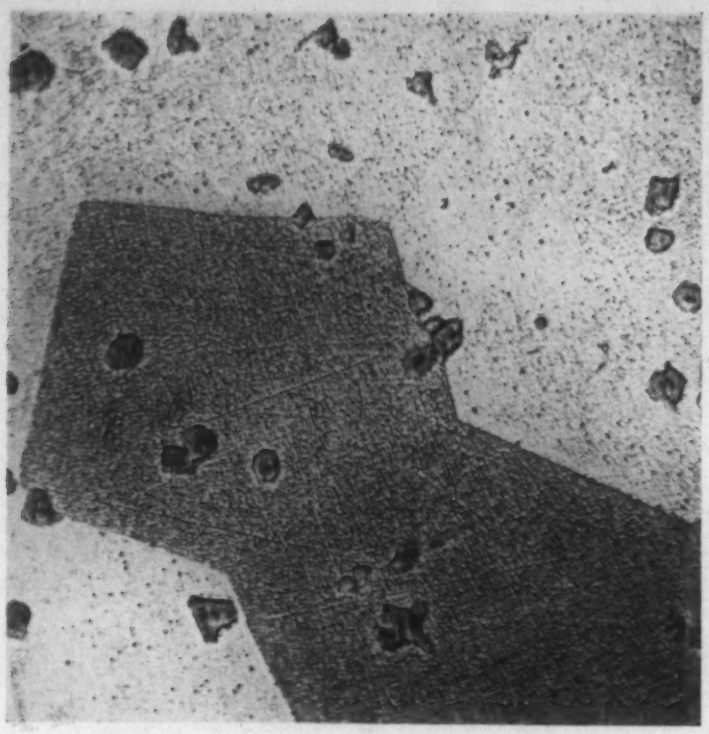


Fig. 8A. Same as Fig. 8 but at 500 X.

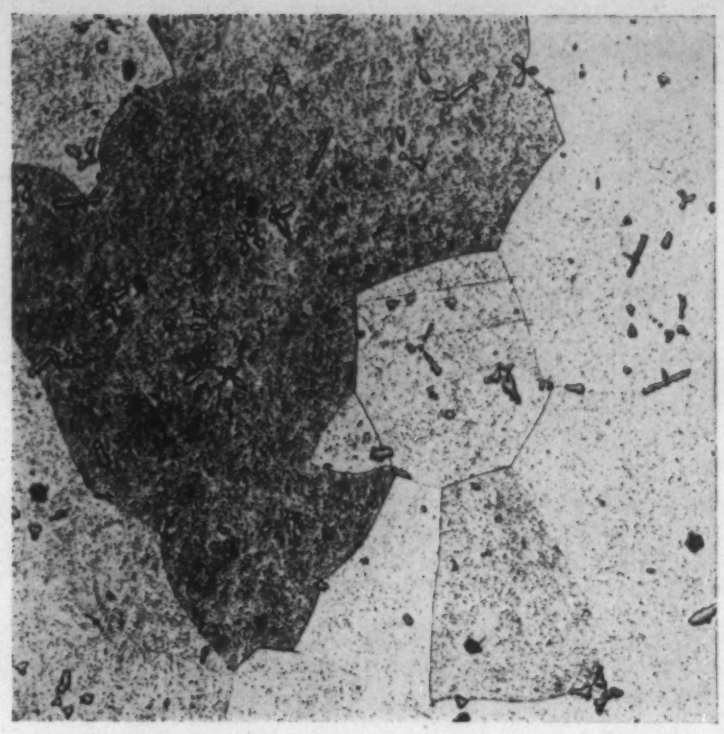


Fig. 9. Photomicrograph of Heat No. 325 Shows Coarse Beta Grains. 100 X.

Fig. 9A. Same as Fig. 9 but at 500 X.

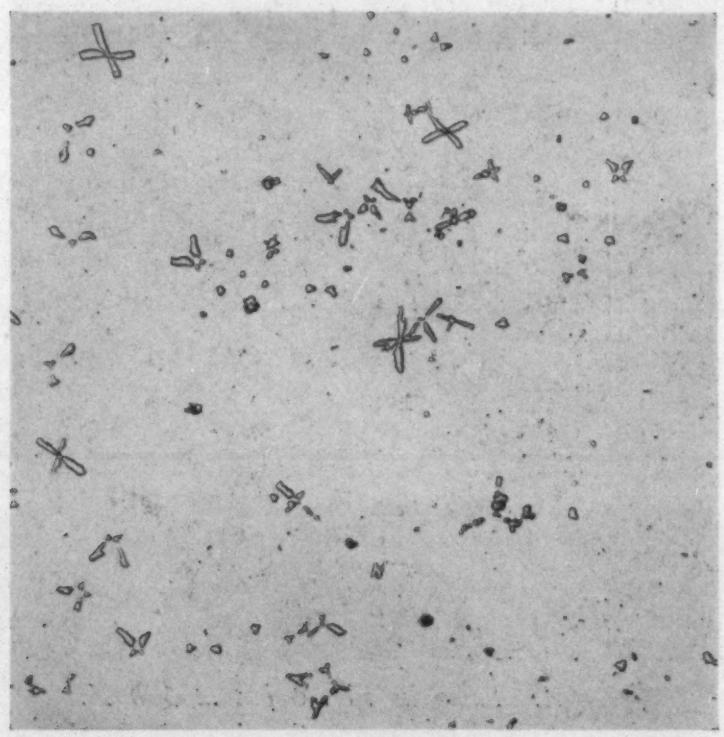
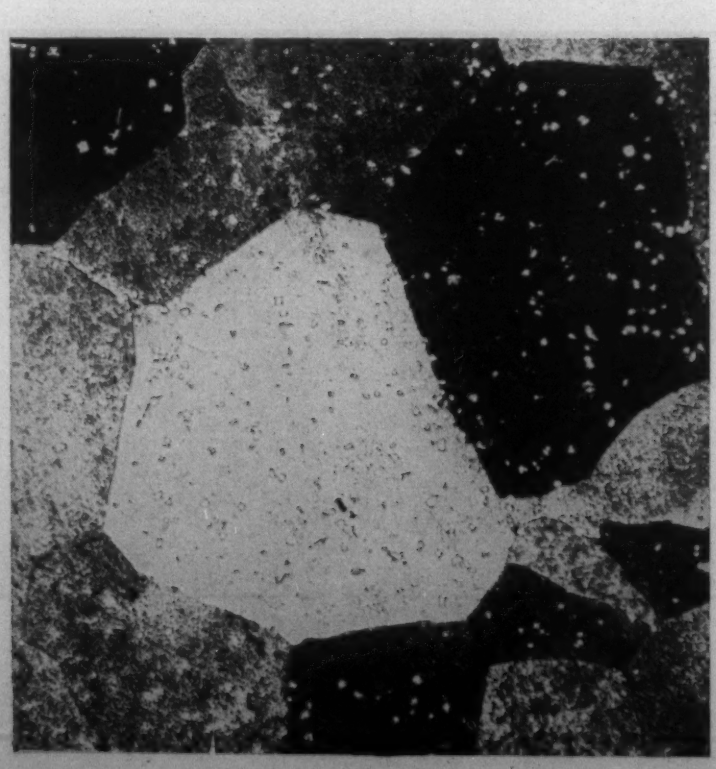


Fig. 9B. Same as Fig. 9 but Unetched. 100 X.

Fig. 10. Photomicrograph of Heat No. 390 Shows Coarse Beta Grains. 100 X.

Fig. 10A. Same as Fig. 10 but at 500 X.



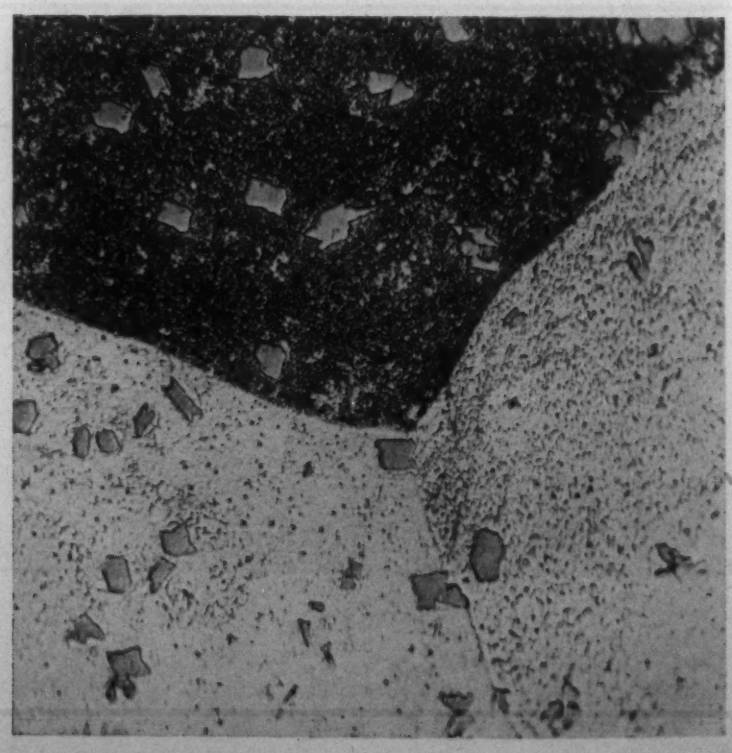


Table VI—Brinell Results on Experimental Heat Treatments

	Heat No.	Brinell As-cast	Solution Treatment: Temp., deg. F.	Hold	Coolant	Aging Treatment: Temp., deg. F.	Hold	Coolant	Brinell	Difference
(1)	465	193	1700	1 hr.	water	....	....	.....	200	+ 7
(2)	465	193	1700	1 hr.	air	....	....	.....	193	0
(3)	465	193	1700	1 hr.	furnace	....	....	.....	167	—26
(4)	465	193	1700	1 hr.	water	1250	1 hr.	furnace	190	— 3
(5)	358	187	1650	1 hr.	water	....	....	.....	207	+27
(6)	358	187	1650	1 hr.	water	1200	2 hrs.	furnace	197	+10
(7)	5	138	1650	1 hr.	water	....	....	.....	207	+69
(8)	5	138	1650	1 hr.	water	1000	4 hrs.	air	202	+64
(9)	5	138	1650	1 hr.	water	1200	4 hrs.	air	183	+45
(10)	52	228	1650	1 hr.	water	....	....	.....	Cracked	
(11)	52	228	1650	1 hr.	air	....	....	.....	228	0
(12)	52	228	1650	1 hr.	furnace	....	....	.....	228	0
(13)	5	138	1550	1 hr.	water	....	....	.....	207	+69
(14)	5	138	1550	1 hr.	water	1200	4 hrs.	air	170	+32
(15)	5	138	1550	1 hr.	air	....	....	.....	149	+11
(16)	5	138	1550	1 hr.	furnace	....	....	.....	138	0
(17)	358	187	1500	1 hr.	water	....	....	.....	192	+ 5
(18)	358	187	1500	1 hr.	water	900	3 hrs.	furnace	197	+10
(19)	358	187	1500	1 hr.	furnace	....	....	.....	167	—20
(20)	358	187	1350	1 hr.	water	....	....	.....	197	+10
(21)	358	187	1350	1 hr.	water	600	4 hrs.	furnace	212	+25
(22)	465	193	1250	1 hr.	water	....	....	.....	207	+14
(23)	465	193	1250	1 hr.	furnace	....	....	.....	179	—14
(24)	358	187	1200	1 hr.	water	....	....	.....	207	+20
(25)	148	212	1075	2 hrs.	water	....	....	.....	212	0
(26)	334	165	1075	2 hrs.	water	....	....	.....	163	— 2
(27)	148	212	975	2 hrs.	water	....	....	.....	212	0
(28)	334	165	975	2 hrs.	water	....	....	.....	165	0

to discover these treatments was made in the manner shown in Table VI. Preliminary exploration for the solution and aging temperatures was made solely with the Brinell hardness test on specimens 1-in. round by 4-in. long.

The treatments tried in Table VI seemed to indicate that softness could be induced in the metal with slow cooling from temperatures of 1650 to 1200 deg. F., and that comparatively soft specimens could be hardened by either rapid cooling (quenching in water) from 1650 to 1200 deg. F., or rapid cooling followed by aging at 1200 to 1000 deg. F.

To test more thoroughly the effectiveness of some of the more promising of these treatments, and on larger sized specimens (cast test coupons), several bars were treated and then machined into tensile specimens. Table VII contains a description of these treatments and shows the effect of each on tensile properties.

Summarizing the data on heat treatment, it is stated that water quenching is damaging to trunnion bearing metal, not infrequently embrittling it to the point of spontaneous cracking upon exposure to comparatively light stresses.

Table VII—Showing the Effect of Heat Treatment on Tensile Properties

Heat Treatment

	Heat No.	Temp., deg. F.	Hold	Coolant	Temp., deg. F.	Hold, hrs.	Coolant
(1)	51	1650	1 hr.	water			
(2)	51	1650	1 hr.	water	1200	4	air
(3)	370	1600	1 hr.	water	1300	2	air
(4)	370	1600	1 hr.	water	750	2	air
(5)	370	1600	1 hr.	water	300	2	air
(6)	397	1600	1 hr.	water	300	2	air
(7)	358	1500	1 hr.	water			
(8)	379	1500	1 hr.	air			
(9)	380	1500	1 hr.	furnace			
(10)	400	1450	1 hr.	air			
(11)	362	1450	1 hr.	furnace			
(12)	398	1450	1 hr.	furnace			

Physical Properties

		As-Cast: Tensile Strength, lbs. per sq. in.	Yield Point, lbs. per sq. in.	Elongation, per cent	Red. Area, per cent	Treated: Tensile Strength, lbs. per sq. in.	Yield Point, lbs. per sq. in.	Elongation, per cent	Red. Area, per cent
(1)	51	92,000	54,150	5.0	7.00	Cracked in lathe			
(2)	51	92,000	54,150	5.0	7.00	78,250	52,500	5.0	10.50
(3)	370	112,000	83,500	14.0	17.39	62,000	.....	1.5	....
(4)	370	112,000	83,500	14.0	17.39	66,750	.....	1.0	....
(5)	370	112,000	83,500	14.0	17.39	111,000	95,000	5.5	11.90
(6)	397	101,500	60,000	18.0	20.50	Cracked in lathe			
(7)	358	94,500	55,000	15.5	20.00	80,250	76,500	1.5	2.76
(8)	379	113,750	81,750	14.0	17.39	113,000	83,250	13.0	15.50
(9)	380	115,750	84,750	13.0	15.58	114,500	85,250	12.5	16.67
(10)	400	101,500	59,000	16.0	20.50	107,500	72,750	11.0	13.02
(11)	362	115,500	82,250	17.0	19.89	113,250	80,750	16.0	20.24
(12)	398	104,750	64,500	15.0	17.75	100,500	58,000	14.0	17.75

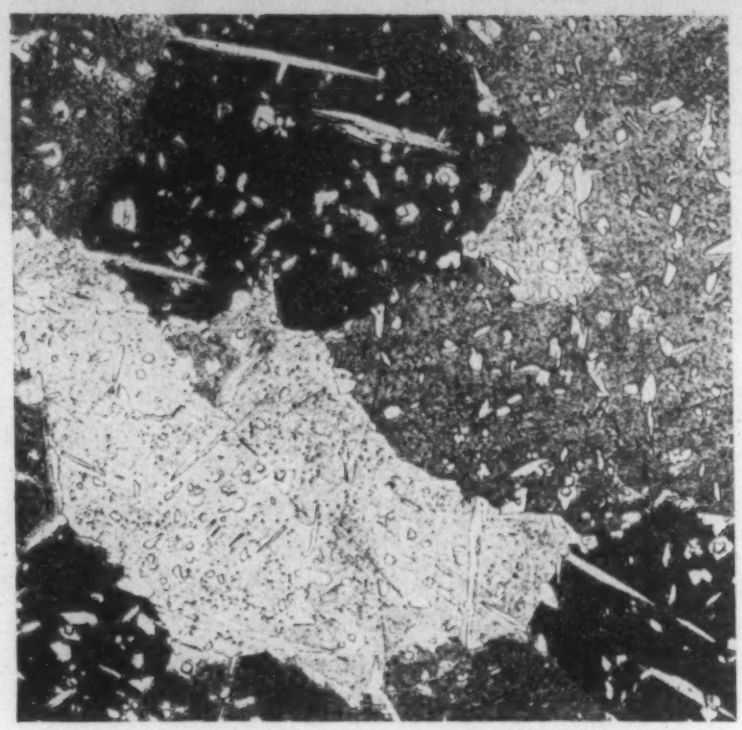


Fig. 11. Photomicrograph of Heat No. 51 Shows Long Slender Shafts of Alpha in Large Grains of Beta. 100 X.

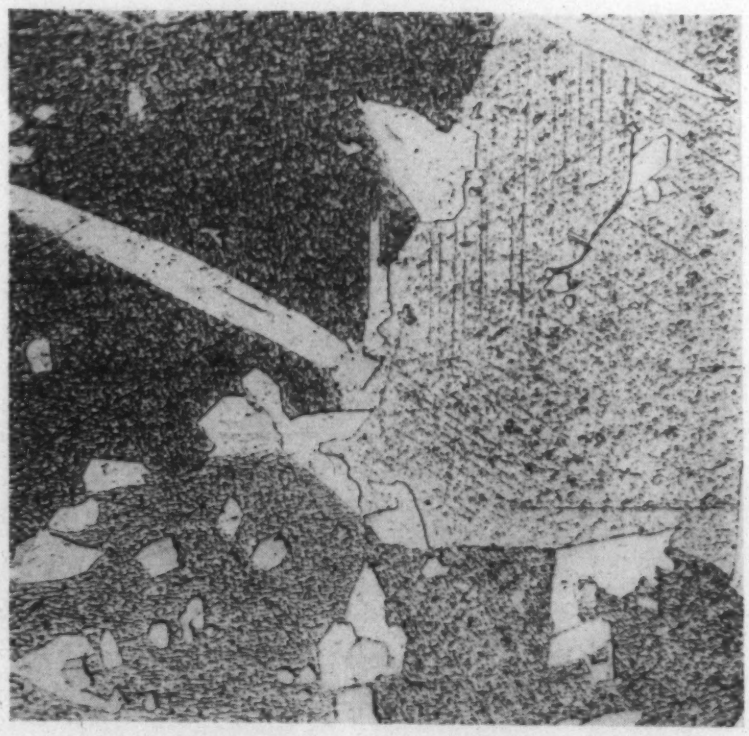
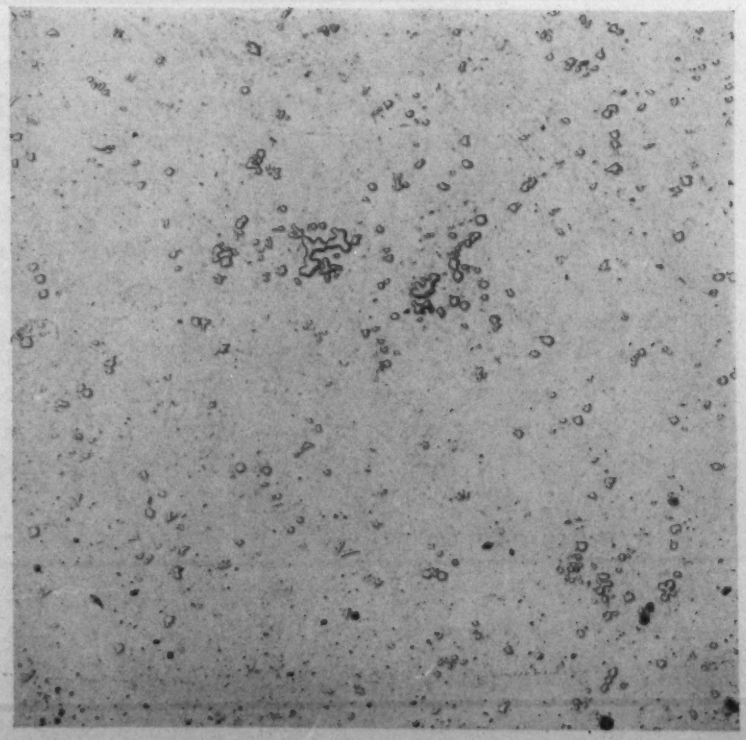


Fig. 11A. Same as Fig. 11 but at 500 X.

Fig. 11B. Same as Fig. 11 but Unetched. Fe-Zn crystals present.



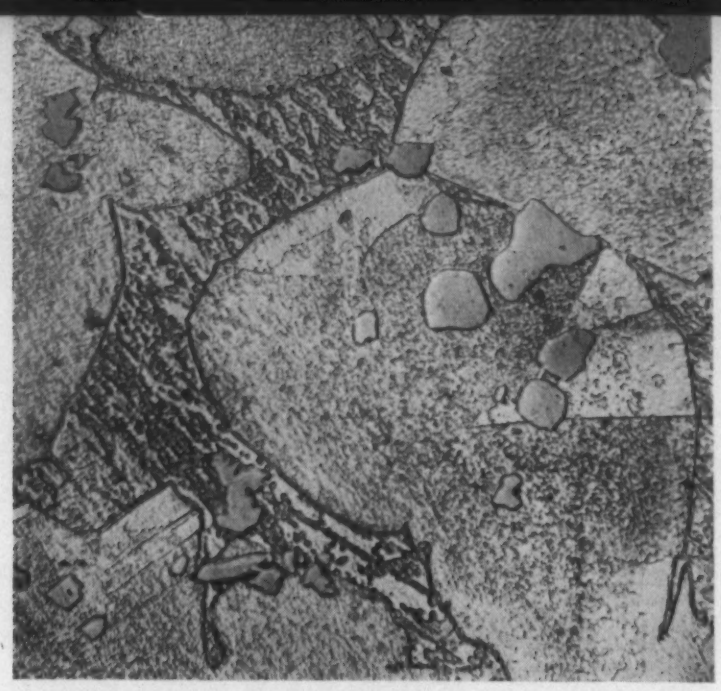


Fig. 12. (Left) Photomicrograph of Heat No. 333A Shows Alpha Enmeshed in a Network of Comparatively Brittle Material. 100 X. Fig. 12A Same as Fig. 12 but at 500 X.

Fractures of water quenched specimens were found to consist of very regular crystals having smooth, almost rectilinear outlines. The slow cooling treatments, though not harmful to tensile properties, are of doubtful value from the standpoint of economy.

SUMMARY AND CONCLUSIONS

A WAY of making good trunnion bearing metal has been described. Essentially, it consists of: (1) alloying definite quantities of virgin metals; (2) pigging the alloyed metal; (3) remelting the pigs with suitable admixtures of aluminum and zinc at temperatures not exceeding 2050 deg. F.; (4) maintaining the metal at these temperatures for a standardized holding time so as to limit the loss of zinc and other elements; (5) and pouring the metal at the lowest possible temperature consistent with good foundry pouring practice.

If for some reason a heat has been made incorrectly, or from pigs whose composition is not known, and tensile tests from the remelted metal indicate sufficient strength but insufficient ductility, the metal is most likely high either in aluminum or zinc, or both, and can best be made ductile by a third remelting without any but a deoxidizing addition. The length of holding time at the melting temperature should be proportional to the amount of ductility required. Every 10 min., of holding time at a melting temperature of 2050 deg. F. is approximately equivalent to a pick up of 2.0 per cent elongation. Just the required amount of ductility should be aimed for, and no more. Overholding the metal will lower its tensile strength below the specified limit. If, on the other hand, tests show the metal to be sufficiently ductile but deficient in strength, a very small amount of aluminum and zinc, in the ratio of 1:4 will strengthen it. For the compositions shown in Table III, every 1.0 per cent zinc plus 0.25 per cent aluminum will raise the tensile strength by approximately 3500 lbs. per sq. in.

This paper is not intended to present a complete answer to the problem of producing cast trunnion bearing metal. It is hoped, however, that it will serve to clarify some of the factors involved therein and assist the foundryman in producing consistently good trunnion bearing metal.

Acknowledgment

The author is pleased to acknowledge the support and helpful suggestions of S. W. Brinson, master moulder at the Navy Yard. A word of sincere appreciation is also due T. Moseley, who assisted in carrying out much of the experimental foundry work connected with the preparation of this paper.

Editorial

(Continued from page A 23)

pearlite" as qualitative expressions, to bridge the gap between lamellar pearlite and primary troostite. We don't like the emulsified pearlite phrase very well and are hoping someone will suggest a better, but it struck us as more descriptive than to try to make sorbite cover this as well as the meaning, that no one will want to take away from it, of a decomposition product of martensite.

Thus, by starting with a desire to keep sorbite straight, we wound up with a use of pearlite that does not require it to be clearly lamellar in structure, nor to be a result of equilibrium conditions. We never do reach equilibrium conditions, anyway.

Having defined the way he is using the terms, any writer is free to use what terms he will, whether or not some committee has put the stamp of approval on those particular definitions. If they make sense, other writers will use them, too.

It seems to us personally that the way for such matters to be settled is as follows:

1. Let attention be called to the ambiguity—Prof. Sauveur has done this forcefully.
2. Let those who are sufficiently interested set forth what the word means to them and the process of reasoning by which they come to feel that that word should have that meaning.
3. Let nature take its course, *i.e.*, let other people decide what it means to them and use it to denote such meaning.
4. Then, and only then, let an A.S.T.M. Committee, or a lexicographer, report what accepted usage has come to be.
5. When new information comes in to add some further shade of meaning and again create ambiguity—do it all over again.

We seem to be in Stage 1 at present, in regard to the words Prof. Sauveur is discussing. Hence we invite those interested to enter Stage 2 and send in their comments for publication.

We think the matter will really be settled by usage based on logic, rather than by edict of a past or future committee,

(Continued on page 148)

INFLUENCE OF OXYGEN ON THE

Aging of Iron and Steel

Part II

(Concluded from the May Issue)

by A. B. Wilder

Assistant Professor of Metallurgical Engineering, University of Illinois, Urbana, Ill.

Quench Aging of Low Carbon Steels

Low carbon steels without and with various deoxidizers including aluminum, manganese, and silicon were quenched and aged. The results are given in Table 4 and Fig. 7. Wrought iron, although high in oxygen, did not quench-age harden to the same extent as the various steels low in oxygen. The steel deoxidized with aluminum exhibited less age hardening than the other steels. It should be observed that the hardness of the aluminum deoxidized steel after quenching was greater compared to the other steels. This indicated aging in the quenching bath and accounts for less quench aging as the actual grain size of the various samples was quite similar. The age hardening of the low carbon steels may be satisfactorily explained upon the basis of carbon with oxygen playing a secondary part.

Table 4.—Quench Aging of Low Carbon Steels Quenched from 1742 Deg. F. (950 Deg. C.) in Water. Maximum Increase in Brinell aHrdness after 30 Days Aging.

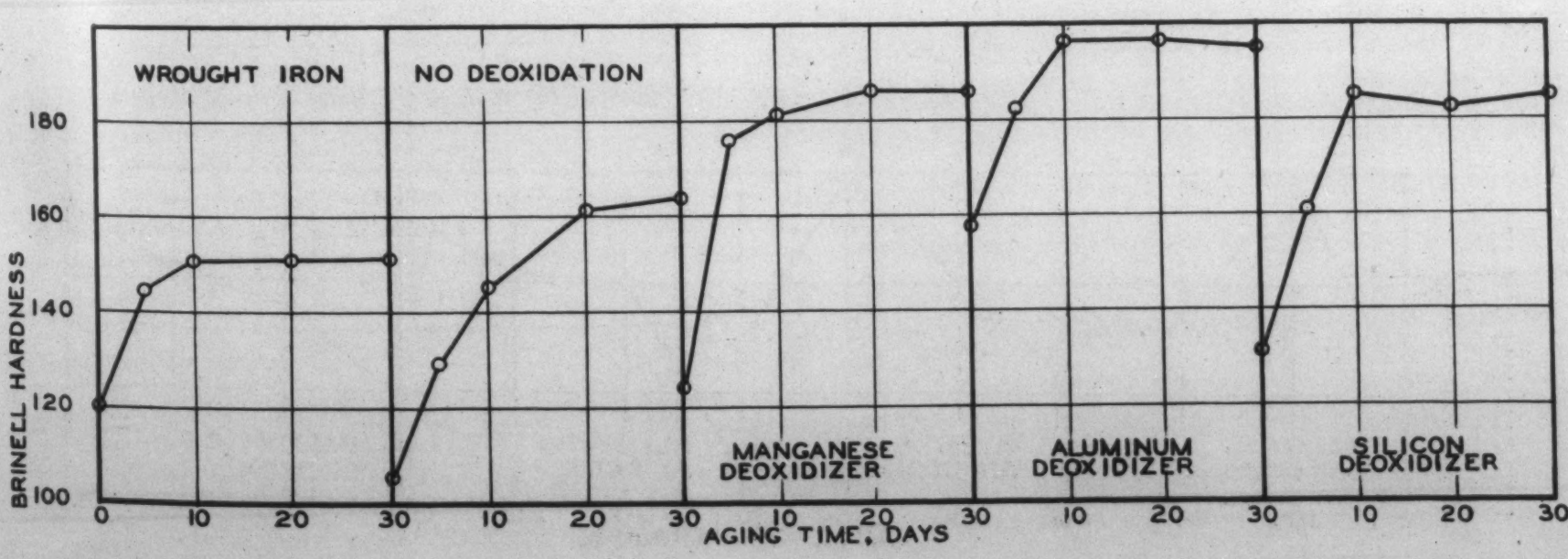
Steel No.	4 (Wrought Iron)	5 (No De-oxidation)	6 (Mn De-oxidizer)	7 (Al De-oxidizer)	8 (Si De-oxidizer)
Max. increase in hardness	30.8	48.0	62.0	38.9	54.0

Artificial Strain Aging of Low Carbon Steels

It may be observed from Table 5 and Fig. 8 and 9 that the maximum hardness obtained from artificial strain-aging of various low carbon annealed steels occurs at different temperatures and time intervals. All the low carbon steels exhibited marked strain aging, aluminum deoxidized steel being no exception. The production of non-aging steel does not depend, alone, upon the addition of a strong deoxidizer. The conditions at the time of deoxidation are important and a suitable heat treatment of the rolled steel is usually essential. The author is aware of many unsuccessful attempts on the part of steel makers to manufacture non-strain-aging steels, because of uncontrolled conditions at the time of deoxidation and solidification.

The final hardness values produced by artificial aging are the same, if not greater, than the results obtained by nat-

Fig. 7.—Quench Aging of Low Carbon. Alloys No. IV, V, VI, VII, VIII; quenched from 950 deg. C.



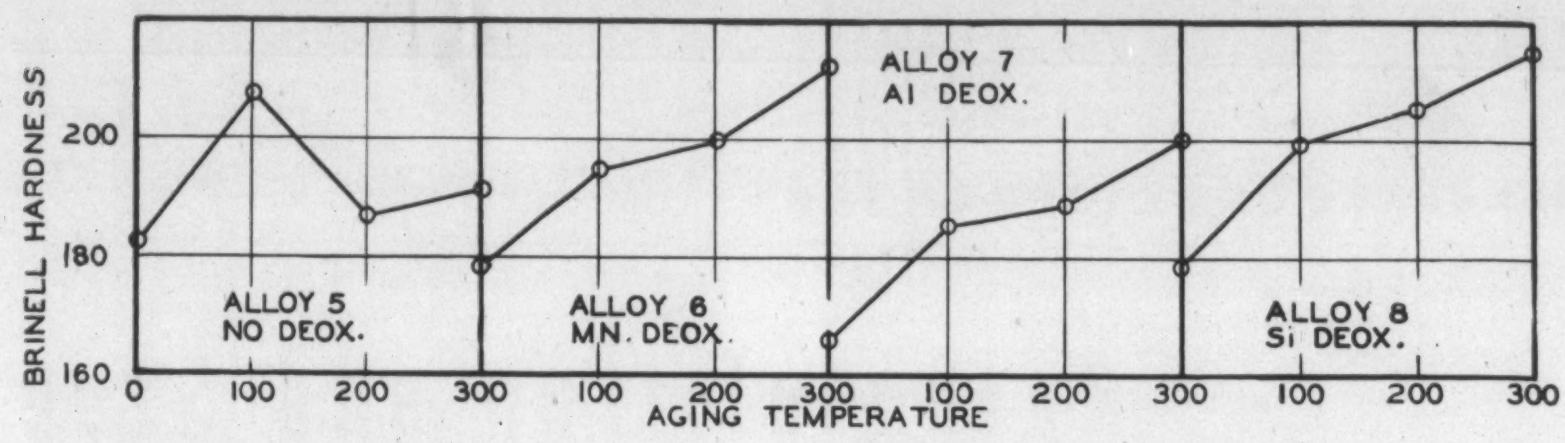


Fig. 8.—Strain Aging of Low Carbon. Alloys No. V, VI, VII, VIII; annealed 950 deg. C; aging time 15 mins; 3000 kg. Brinell load.

ural or room temperature aging. The fact that these steels behave differently during artificial aging suggests a precaution to be observed in such observations. The similarity of natural and artificial aging is only expressed by the hardness readings in this investigation. The actual mechanism may be different.

Strain Hardening Susceptibility

The results obtained from strain aging annealed and heat-treated special deoxidized 0.19 per cent carbon steel are expressed in Table 6 and Figs. 10 and 11. The results are illuminating in that steel exhibiting practically no strain age hardening was produced by special heat treatment after suitable deoxidation. Quenching from 1652 deg. F. (900°C.) and annealing at 1202 deg. F. (650°C.) produced a favorable condition contributing toward the non-aging property of this steel. Izett steel has long been known as a non-aging steel and this property has been explained by special deoxidation and heat treatment. It is also recognized that the solubility of oxygen decreases as the carbon content increases. The heat-treated steel had a sorbitic structure, hence the absence of islands of free ferrite. However, it will be recalled that Armco iron responded to this treatment to a certain degree, although sorbite was absent.

The properties of a non-aging steel of the type discussed originate in the deoxidation practice. It is believed that proper deoxidation in combination with heat treatment, produces a condition in steel that removes oxygen from a state favorable toward strain aging. Sometimes cooling in air from temperatures above the critical range may replace the quenching treatment. However, in the present investigation, quenching from above the critical range and annealing below the critical range have produced the most satisfactory steel with non-aging properties.

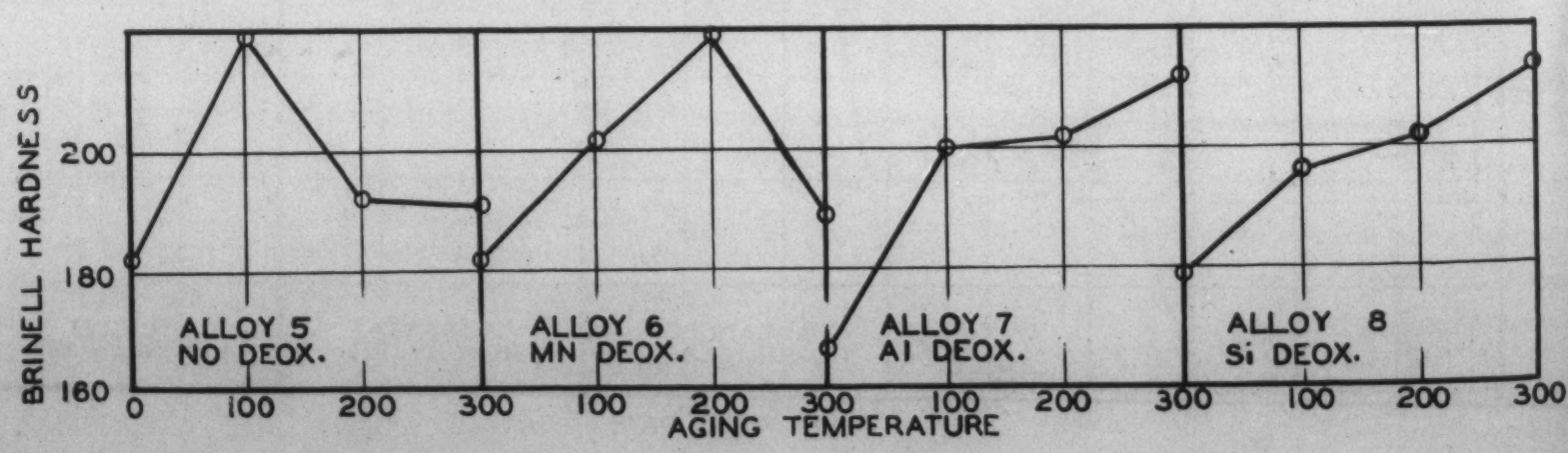
In Table 6 and Fig. 10 it will be noted that simple annealing exhibited marked strain aging. It is possible that carbon is the cause of the age hardening and a suitable heat treatment stabilizes the element. Little age hardening occurs after the special heat treatment. However, the results obtained with pure iron-oxygen alloys indicate that oxygen is the element stabilized by heat treatment. This steel contains an ample amount of carbon, hence the absence of oxygen suitable for precipitation may be the cause of non-aging. The commercial production of non-strain-aging steels by suitable deoxidation and heat treatment has become common practice.

Table 5.—Artificial Strain Aging of Low Carbon Steels in Brinell Hardness, (Cold worked 3000 kg. Brinell after annealing hot worked steel from above the critical range without special heat treatment.)

Steel No.			5 (No Deoxidation)	6 (Mn Deoxidation)	7 (Al Deoxidation)	8 (Si Deoxidation)
Temp. Deg. F.		Time Min.				
77	(25° C.)	0	182.0	182.0	166.0	178.5
212	(100° C.)	15	208.0	194.0	185.0	199.0
212	(100° C.)	30	*219.0*	202.0	200.0	196.0
392	(200° C.)	15	187.0	200.0	189.0	195.0
392	(200° C.)	30	192.0	*219.0*	201.5	201.5
572	(300° C.)	15	191.5	212.0	200.5	*213.0*
572	(300° C.)	30	191.0	189.0	*212.0*	213.0
77	(25° C.)	30 days	212.0	226.0	212.0	215.0
Max. increase in hardness from heating..			37.0	37.0	46.0	34.5

The marked strain aging in the annealed specimens after a small amount of cold work is of interest. As the degree of cold working increases to a certain point the degree of age hardening increases. Greater applications of cold work decrease the amount of strain aging, until a point is reached in which it does not occur. This may be explained by assuming that age hardening occurs during cold working.

Fig. 9.—Strain Aging of Low Carbon. Alloys No. V, VI, VII, VIII; annealed 950 deg. C; aging time 30 mins.; 3000 kg. Brinell load.



The more severe the cold work, the greater the age hardening during the operation. Provided the steel is not of a non-aging type, these data indicate that the hardness produced by cold working is partially due to instantaneous aging.

Table 6.—Strain Aging of Special Deoxidized Steel No. 9, Maximum Increase in Brinell Hardness after 30 Days Aging.

Brinell load, kg. for cold working	125	500	1000	2000	3000
ANNEALED 1652 DEG. F. (900° C.)					
Max. increase in hardness	37.5	42.5	9.0	7.0	0.7
QUENCHED IN WATER 1652 DEG. F. (900° C.) ANNEALED 1202 DEG. F. (650° C.)					
Max. increase in hardness	6.0	1.0	7.0	1.0	7.0

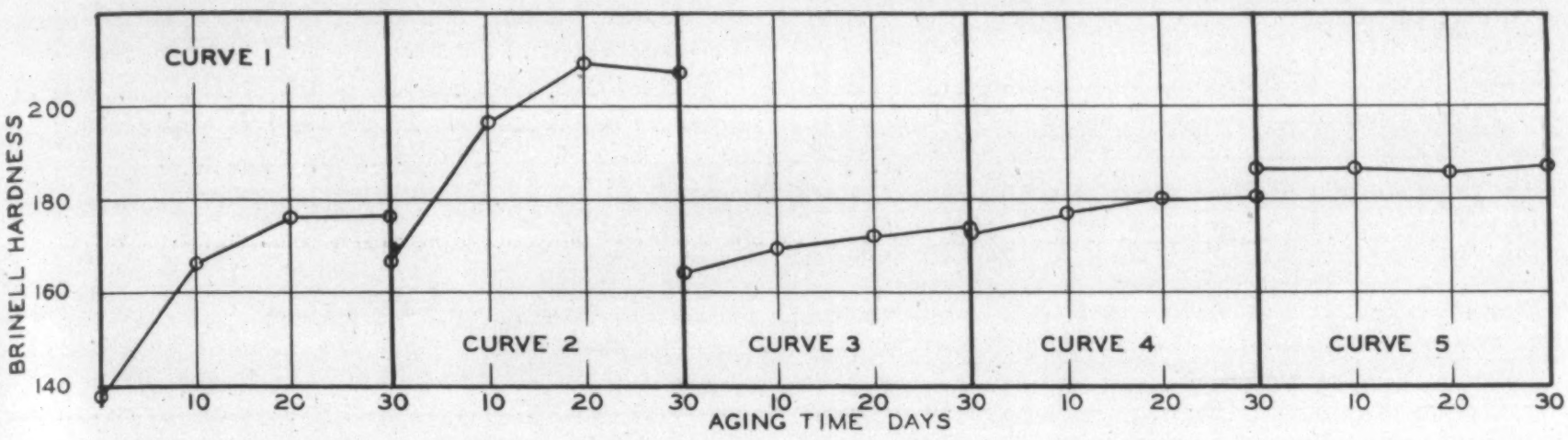


Fig. 10.—Strain Aging of Special Deoxidized Alloy No. IX after Annealing from 900 deg. C. Curve 1—125 kg. Brinell load; Curve 2—500 kg. Brinell load; Curve 3—1000 kg. Brinell load; Curve 4—2000 kg. Brinell load; Curve 5—3000 kg. Brinell load.

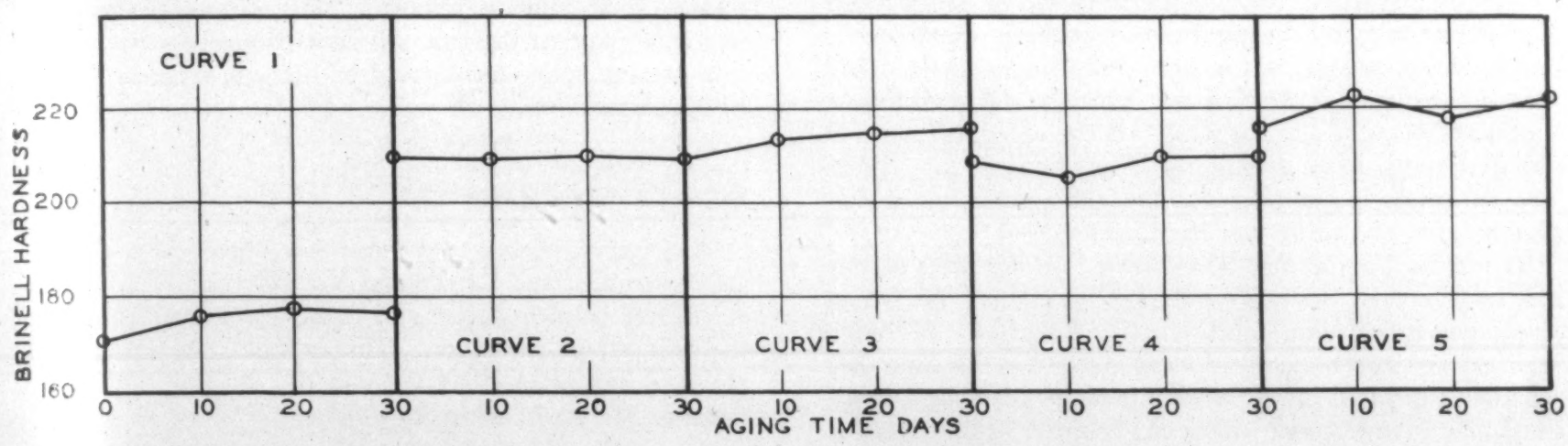


Fig. 11.—Strain Aging of Special Deoxidized Alloy No. IX after Quenching from 900 deg. C. Followed by Annealing at 650 deg. C. Curve 1—125 kg. Brinell load; Curve 2—500 kg. Brinell load; Curve 3—1000 kg. Brinell load; Curve 4—2000 kg. Brinell load; Curve 5—3000 kg. Brinell load.

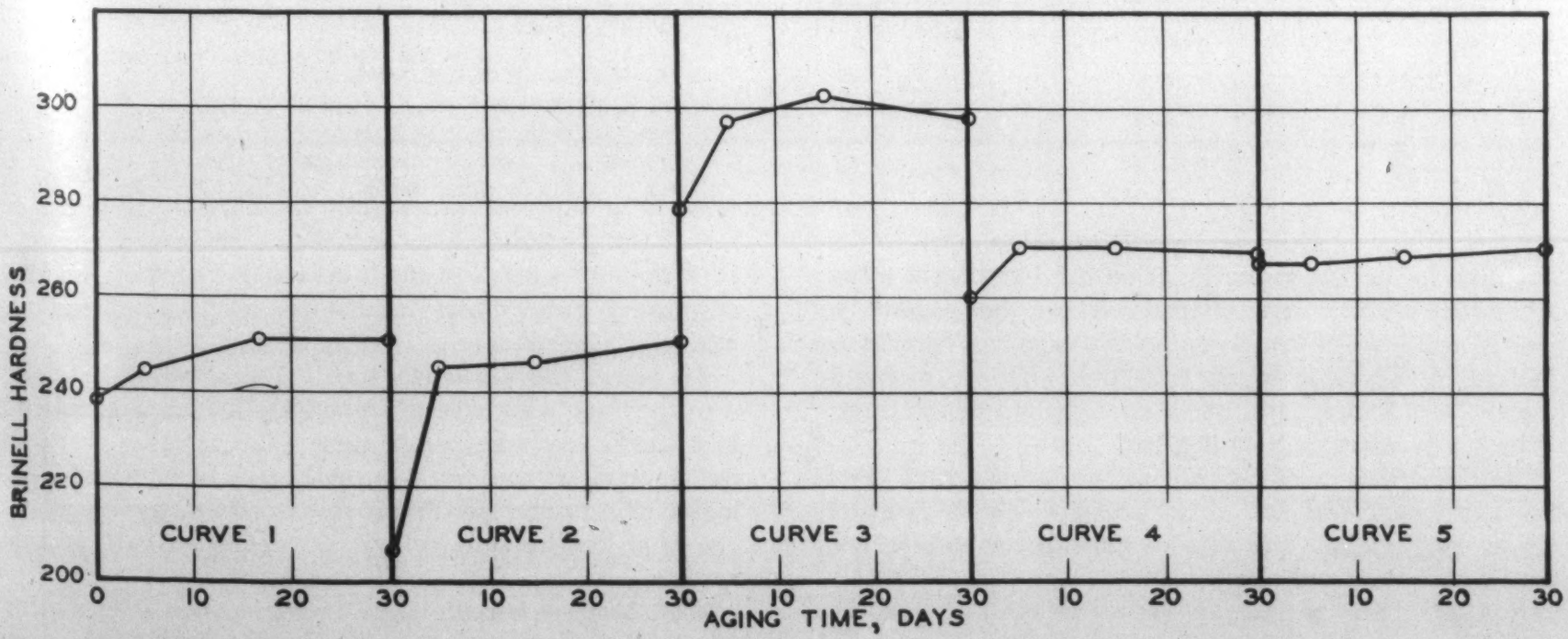


Fig. 12.—Quench and Strain Aging of Carburized Armco Iron. Curve 1—Alloy No. X quenched from 650 deg. C., no cold work; Curve 2—Alloy No. XI quenched from 650 deg. C., no cold work; Curve 3—Alloy No. XI quenched from 650 deg. C., 500 kg. Brinell, cold work; Curve 4—Alloy No. XI quenched from 950 deg. C. followed by annealing at 650 deg. C., 500 kg. Brinell load, cold work; Curve 5—Alloy No. XI annealed 950 deg. C., 500 kg. Brinell load, cold work.

Quench and Strain Aging of Carburized Iron

High carbon steel with an appreciable amount of oxygen may be obtained by box carburizing. Armco iron was box carburized and then treated before aging. The results in Table 7 and Fig. 12 show marked aging under certain conditions of treatment.

Steel No. 11 was carburized 75 hrs. and Steel No. 10 24 hrs. Marked age hardening will be observed in Steel No. 11 after quenching from 1202 deg. F. (650°C.). This particular steel did not age harden in the quenching bath like the one carburized 24 hrs. and this accounts for the marked difference in aging properties. The steel quenched at 1202 deg. F. (650°C.) and cold worked did not age harden to the same extent as the steel without cold work. This is due to aging during the cold working operation.

Results are not given for steel carburized and quenched from 1742 deg. F. (950°C.) but it may be stated that these specimens did not age harden. All the aging occurred in the quenching bath during the formation of martensite. The annealed specimens exhibited little strain aging, especially after the full annealing treatment.

The quench aging may be explained on the basis of carbon with oxygen acting as a secondary factor. The strain aging may be explained on the basis of oxygen. Although high carbon steels usually do not strain age harden, they are low in oxygen. It is possible that the carburized specimens may have retained sufficient oxygen to account for the aging observed.

Table 7.—Aging of Carburized Armco Iron Alloys No's. 10 and 11. Maximum Increase in Brinell Hardness after 30 Days Aging.

Treatment	Q* 1202° F. (650° C.)	Q 1202° F. (650° C.)	Q 1202° F. (650° C.)	Q 1742° F. (950° C.) A† (650° C.)	A 1742° F. (950° C.)
	No cold work	No cold work	Cold worked 500 kg. Brinell	Cold worked 500 kg. Brinell	Cold worked 500 kg. Brinell
Steel No.	10	11	11	11	11
Max. increase in hardness	12.0	45.4	24.0	10.5	3.5

* Quenched in water. † Annealed.

Conclusions

1. The aging of steel after quenching is due to the precipitation of a carbide. Oxygen has a secondary part in quench aging.

2. The aging of steel after cold working, for the most part, is due to the precipitation of an oxygen compound.

3. The hardness of cold-worked steel may, to a certain degree, be caused by aging during the cold-working operation.

4. Aging of low and high carbon steels may occur in the quenching bath. The effect depends upon the nature and composition of the steel.

5. Steel that exhibits little, if any, strain aging may be produced by proper deoxidation and heat treatment.

6. It is believed that a new approach to the problem of age hardening in steel would prove to be very fruitful. The present investigation makes no attempt to outline the procedure, but emphasizes for example the need for determining solid solution oxygen. The control of conditions in molten steel at the time of deoxidation for the preparation of non-aging steel should be defined in terms of equilibrium conditions.

Acknowledgments

The author wishes to express his appreciation to Prof. Albert Sauveur and Dr. Leland Van Wert of Harvard University for helpful advice and constructive criticism during the progress of the work. The experimental results were obtained during 1931 to 1933 in the metallurgical laboratories of Harvard University.

[12] C. H. Herty, Jr. & co-workers. "The Physical Chemistry of Steel Making." "The Solubility of Iron Oxide in Iron," 1st edition, 1927. Carnegie Inst. Tech., Pittsburgh, Pa.

[13] J. A. Thompson, H. C. Vacher & H. A. Bright. "Cooperative Study of Methods for the Determination of Oxygen in Steel," *Trans.*, Am. Inst. Mining Met. Engrs., Vol. 125, 1937, p. 246.

[14] W. Koster. "Der Einfluss einer Warmbehandlung unterhalb A_1 auf die Eigenschaften des technischen Eisens," *Archiv für das Eisenhüttenw.*, Vol. 3, 1929, pp. 503-522.

[15] A. Sauveur. "Notes on the Aging of Metals and Alloys," *Trans.* Am. Soc. Metals, Vol. 22, Jan. 1934, p. 97.

(Continued from page 144)

no matter how eminent. These things settle down in time but they are not amenable to an off-hand verdict at a time when they are in a state of flux. As we stated above, we had to make an off-hand verdict for ourselves because we had to choose some words and state what we meant by them. But nobody else, not even ourselves in the future, is bound by what we then decided.

And in the interests of nomenclature, isn't Prof. Sauveur's word "schism" a bit strong? Words aren't religion, they're tools, and like all tools, become dulled and need reshaping from time to time.

It would be nice if words always meant the same, but they won't stay put. Sometimes a word goes astray and then comes back. "Democrat" meant something different in 1910 and 1933; perhaps in 1940 it will again mean more nearly what it used to. Fortunately steels react the same from year to year, though human beings react differently at different times. So we have a stable set of metallurgical conditions to describe in words and it should be a simple, impersonal task, ultimately to report, as lexicographers rather than legislators, what definitions are generally adaptable.

To hasten the day when such a report might be made, we urge those who have thought these matters out, to send in discussions of the points Prof. Sauveur raises. It may not be necessary to refer it to the League of Nations! Some logical thinker may put things so cogently that, without any official action, his phraseology and definitions will become current.

Prof. Sauveur is quite right in stating that it is not for any small or any large group to decide what our language should be. Every user of the words will make his own choice, (preferably after having considered the logic that led others to their choices) and all any group can do is to report what that choice has been.—H.W.G.

A Few Chuckles

More Electrons in Iron!

To the Editor: Thinking that, in your busy day, you may have missed it, I am sending you a booklet on a certain brand of pig iron. It contains some, to me at least, revelations. The following passages particularly appeal to me, and I am wondering how our electric melting affects the electron equilibrium.

> Let us consider for a moment the electronic theory. A casting is made according to certain specifications and chemical analysis. It is then put into use, subjected to the shock and strain that its duty imposes upon it, and later on it breaks. If it has given average service it is scrapped without further comment and usually replaced by another similar casting.
>
> If the broken casting were sent to the laboratory for analysis, it is quite likely the same elements such as carbon, silicon. phosphorus, manganese, sulphur, etc., would be found, and, unless it had been subjected to wear and abrasion, it would be found to weigh as much as it did originally.
>
> If the broken casting contains the same chemical analysis, and has not lost any appreciable weight, is properly designed and made, what causes it to break after performing its duty properly for a given length of time?
>
> According to one of the electronic theories, the casting or metal has become fatigued, caused by the electrons going off into space during the performance of its duty. If this be so, it is plainly seen why the continued use of scrap over and over is bound to result in inferior castings. Inasmuch as the quality of scrap is such an unknown factor, it becomes more and more essential for the steel maker and foundryman to select the highest grade of pig iron obtainable for the base of his mixture.
>
> From the results obtained by users of our pig iron over a period of a great many years, it is our contention that our ore (of which there is no other similar deposit to be found anywhere) contains either more or an exceptional combination of electrons, or both, than any other known ore, and that these exceptional features carry on into the iron through the process of refinement.

We had some leakers a while ago, and I assume that we probably used gates that had been remelted so many times that the electron content was depleted. Then, when we melted them in the electric furnace, we pumped them full of electrons, probably super-saturating the iron. During freezing, the excess electrons would, of course, be liberated, leaving holes in the casting. We had wondered whether the holes were caused by gas or shrinkage but are now suspicious that we have been on the wrong track. What we needed seems to be an electron stabilizer.

Yours for more electrons in iron.

CARL H. MONKEN,
Superintendent of Operations.

Carondelet Foundry Co.,
St. Louis, Mo.

"Noble Copper"!

To the Editor: Here is a copy of a letter that I have recently received. It is one of those things that brighten up an otherwise gloomy day. I thought you might like it for your "Chuckles."

ALBERT J. PHILLIPS,
Superintendent.

Amer. Smelting & Refining Co.,
Barber, N. J.

Zara, March 20, 1938.

Dear Mr. Phillips: By a special chemical procedure, invented by me, it is possible to transform ordinary copper (Cu) into a new metal, "noble copper," as I call it, possessing all physical and chemical properties of a noble metal, having a yellow tint.

The cost of production would amount to about 400 Italian Lire for each kg. of noble copper, but might be sensible reduced by producing on a large scale.

The process, invented by me, is of the greatest importance and liable to provoke a revolution in chemistry, because it implies the possibility of transforming all metals soluble in nitric acid (HNO_3) into noble ones; it offers moreover a new method whereby to produce profitably hydrates, as for instance petrol, cauis chouk, and, according to my conviction, it enables to imitate nature in artificial production of such materials that are at present only available in their natural state.

The aforesaid chemical process only occurs under special external conditions, that are present actually in nature only at rare occasions. (I had myself the opportunity of utilising such special conditions, during a few days only, in a period of many years.)

I have therefore conceived and studied an apparatus that could artificially realize those special conditions, responsible for the chemical process in question.

To construct such an apparatus, an expenditure between 30,000 and 50,000 Italian Lire is required, a sum, that owing to my financial conditions I never was able to secure. As before mentioned, I was forced to avail myself of those rare opportunities offered by nature, succeeding in experimental production of little quantities of noble copper alone.

If my invention interests you, we might conclude an agreement, regulating the construction of the apparatus, on your expense, the subsequent testing and acquisition of my invention, that in my belief, should not be advisable to patent, at least, for the present.

As I have no means to go to your country and ask from you no other financial support, I believe the best would be for you to provide for the construction of the apparatus somewhere, possibly in a place near or in my residence, where I could direct the work and, when completed, prove the value of my invention.

I should like to have from you an answer including your conditions for the proposed agreement.

I beg not to quote in any case in your reply the specific nature of my invention.

Please possibly correspond in german or french.

[In presenting this unique and interesting communication, editing was purposely omitted.—Editor]

A Freshman's Conception of Metallurgy

To the Editor: The following is an excerpt from a quiz on an introduction to metallurgy. It was written by a freshman. I thought it might be of interest to you for "Chuckles" as an indication of what is really wrong with this old world of ours.

> So it can be observed that, as Metallurgy has grown, so have science and mankind grown. Without metallurgy there could be no civilization. The backward peoples are those who have never been fortunate enough to study metallurgy.

ROY WARD DRIER.

Michigan College of Mining and Technology,
Dept. of Metallurgy,
Houghton, Mich.

Courtesy: American Rolling Mill Co.

Making a Vacuum Fusion Test in the Research Laboratory

What Is Made of Malleable Iron?

by Enrique Touceda

943 Broadway,
Albany, N. Y.

ON receipt of this article, we suggested that it ought to be expanded to deal also with short-cycle and pearlitic malleable, as well as the old stand-by, standard malleable. We were informed, however, that on those scores the industry is in a state of flux. In other words, how can one justly select an example of the newer modifications of malleable as representative, and determine how it compares with standard malleable in production cost, machinability and toughness, when the newer types are themselves being so steadily improved that the comparison might be out of date by the time it was published?

Each of many manufacturers has developed such products to meet certain specific needs. Some have wanted as much ductility as would go with a certain strength, some have wanted strength and rigidity without caring anything for ductility and so on. Under the circumstances the manufacturing condition taken as a whole is decidedly chaotic. Lots of important parts of well known cars have been made of these pearlitic materials; there seems, however, still to be the engineering question how far one should go in this direction.

It seems to us that a most interesting engineering situation is evidenced by the relative slowness of acceptance of the new types of malleable of higher strength but lower ductility and resistance to impact. Regular malleable was used for much the same purposes as it is now, in the days when it was only required to have 5 per cent elongation, so why has not a much stronger and at least equally ductile, pearlitic malleable become a more important engineering material.

Still one must remember that malleable iron of 5 per cent elongation in the olden days was rapidly becoming unsalable. It was always weak and engineers were extremely suspicious of it. The present extended use of the product was without question made possible by the higher and more uniform physical properties which were obtainable regularly by those who put their minds on their jobs. The tensile and impact values reported for the newer malleables apparently do not convey much meaning to the average engineer, at least not enough so that he is as yet willing to go to the use of the material in a very big way. Does this not mean that, after all, the mechanical property tests by which we specify, and think we evaluate, metals, are not full measures in themselves, but merely the language in which service experience is translated into a tongue in which we say "per cent elongation" instead of "tough"?

That the very mediocre notched bar impact resistance of malleable does not mean a lack of utility in shock-resisting service if the parts are properly filleted makes one wonder whether it, as well as pearlitic malleable, may not be truly tough enough to serve in places where the engineer has feared to use them.

The great automobile consumers of malleable iron do not consider the railway or high tension specification as desirable for their purpose. Of the three great producers one makes his own castings and the other two buy theirs. None of the three have ever displayed any interest in the 35018 grade of malleable iron, presumably being influenced either by machinability or foundry considerations.

There is frequently the consideration that advantage cannot be taken of strong material in say an automotive casting because there is no possibility of reducing the section which is already as thin as a foundryman can make it. The engineer may not be much interested in securing greater strength rather than less weight if, as is usually the case, he will also have to incur higher machining costs.

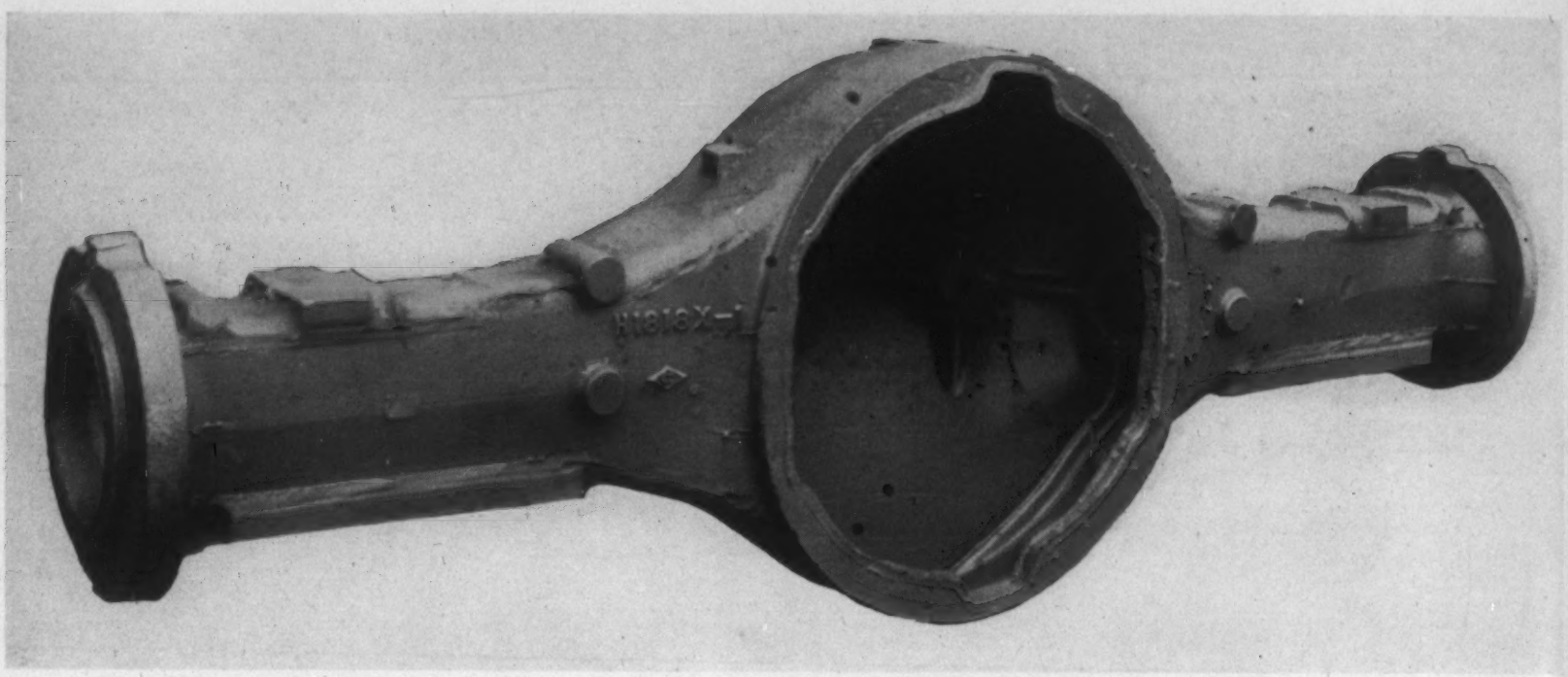
In this general connection, who has data on the damping properties of regular malleable? Does the presence of temper carbon in a ferrite matrix lead to a high damping, like soft cast iron, or to a relatively low damping, like the Ford crank shaft material?—The Editors.

THE INCREASING TEMPO of our commerce and industry is shifting the emphasis, in engineering and application considerations, from a study of static qualities to concern over dynamic and motion properties. There is a distinction between the use of materials in stationary service or controlled conditions and their dependability under shock or moving stresses. There is, therefore, a growing field for working materials which will endure complex stresses.

This need has had much to do with the introduction of alloy grades and specialty products. Among forging bar materials, it has stimulated the development of fine grain steels. In the field of automatically machined parts, there has been an increasing application of higher manganese steels. Among foundry products, there is a growing appreciation of alloy irons.

On the other hand, there has been improvement in many of the older materials. These fundamental improvements in many basic industries and established products may have been less spectacular but are none the less significant in meeting changed conditions or providing a wider range of tough and durable materials.

Malleable iron is a case in point. While not of recent origin, today's product differs appreciably from the "black heart" malleable introduced by Seth Boyden in 1826. This metal's development has been accompanied by changes in its usage and expansion in its field. It is today more usually a component of machines than it is of static structures



A Truck Rear Axle Housing Casting of Malleable Iron. It is 53 in. long and weighs 230 lbs.

although it has elements of quality which make it appropriate for both types of application.

A survey of some of its current uses with an analysis of the reasons for its qualifying in the fields involved serves to indicate its serviceability and working characteristics.

For the Automobile

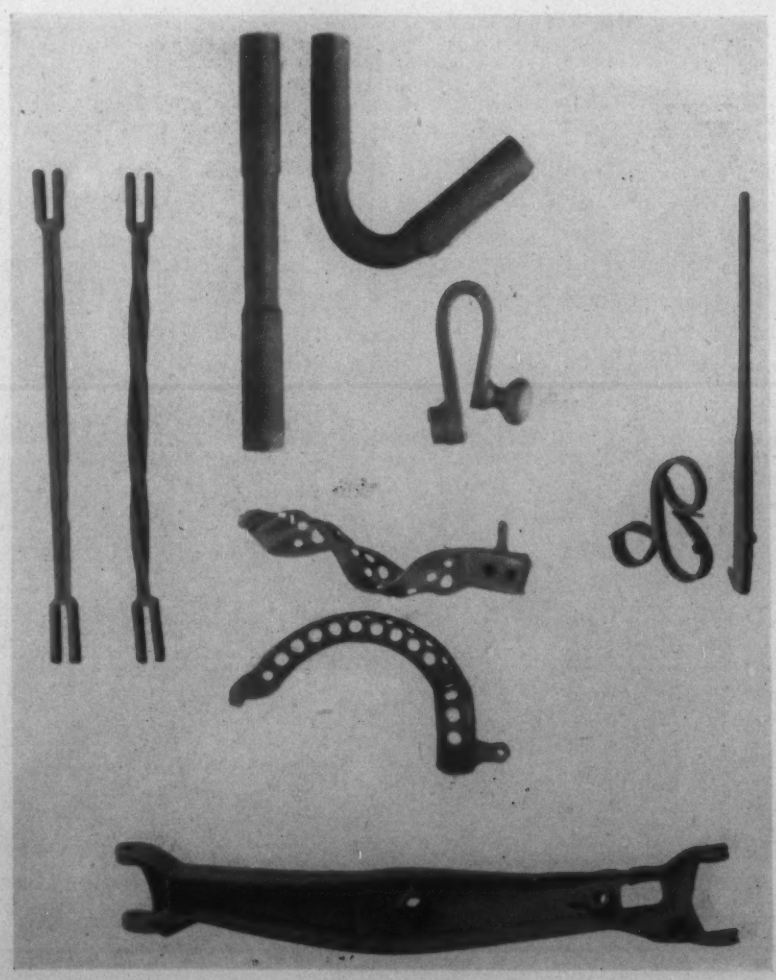
In the automotive field, which consumes a large part of the malleable output, uses are featured in items of safety importance such as axle assemblies, brake and clutch pedals, steering parts, and shock absorbers. Some of these uses are illustrated in the accompanying photographs.

To examine a specific use on automotive parts, the front hub of passenger automobiles is produced from malleable iron. The hub is a vital part of the car mechanism, and it must endure the side thrust of a skidding or swaying car as well as the constant pounding of road jolts.

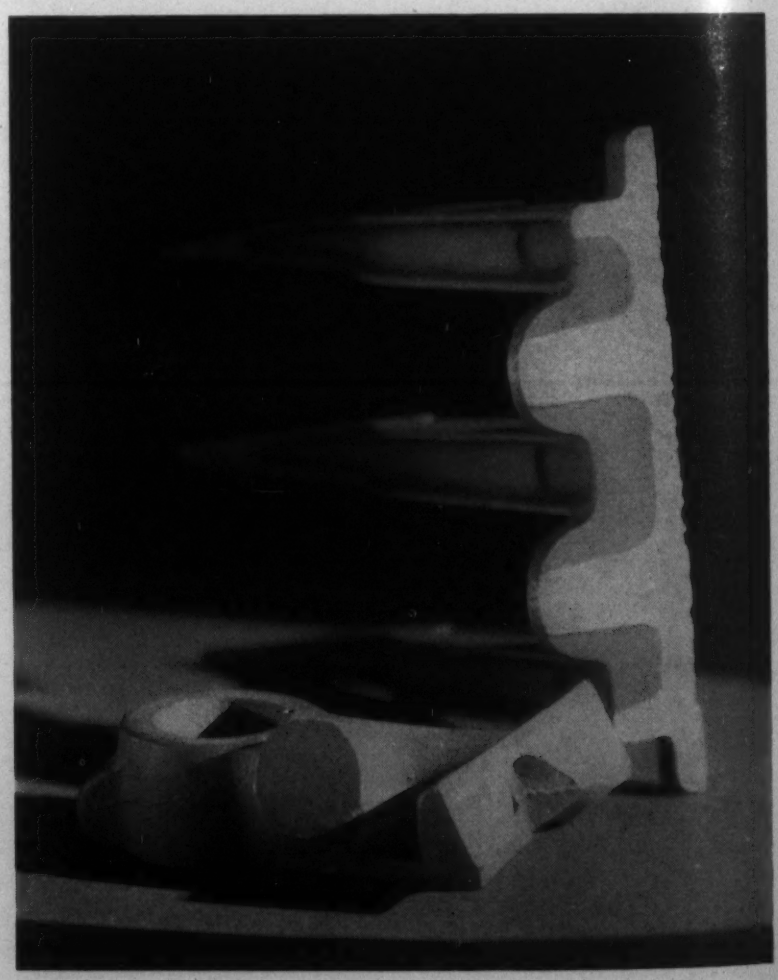
Dual flange hubs, such as are used on the rear wheels of trucks, demonstrate more severe requirements. In a sense, the brake is carried by one flange and the wheel is borne by the other—and sudden stopping imposes conflicting stresses on the cast part.

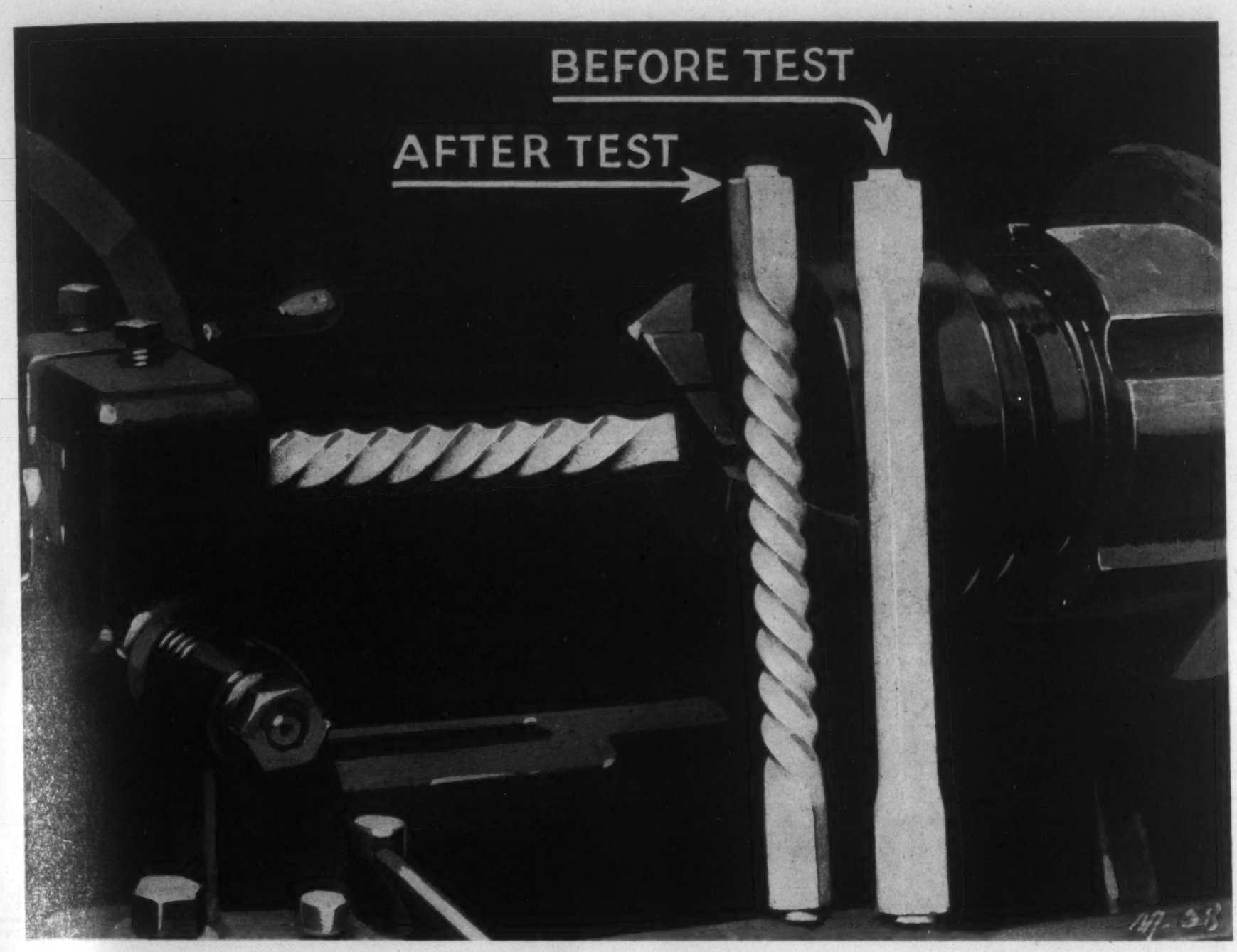
Among the reasons for malleable qualifying on this vital part is a yield point sufficiently high to meet the strength

Malleable Iron Parts after Being Subjected to Abnormal Testing and to Attempts at Destruction.



Two Parts of Cutter Sickle Guard, Made of Malleable Iron, for an Agricultural Implement. The castings are finished by milling machines which are used for removal of gates.





Torsion Testing of Malleable Iron. Test bars are 3/4 in. square at the end and 11 in. long; they endure three or more complete revolutions, 1080 deg., at usual lathe speeds,, without sign of fracture.

requirements. Yet, while presenting this yield point, relatively high in relation to the ultimate strength, due to its very suitable modulus of elasticity, the metal can be subjected to unusual impact or road shocks without snapping or sudden failure. There is, of course, the additional consideration that a casting presents this combination of strength and ductility in all directions of its structure with no necessity for concern over the direction of force application.

For this hub application, malleable iron is able to justify participation because of cost and design advantages as well as by providing ease and speed in machining. This latter facility is an important phase of all automotive parts manufacture.

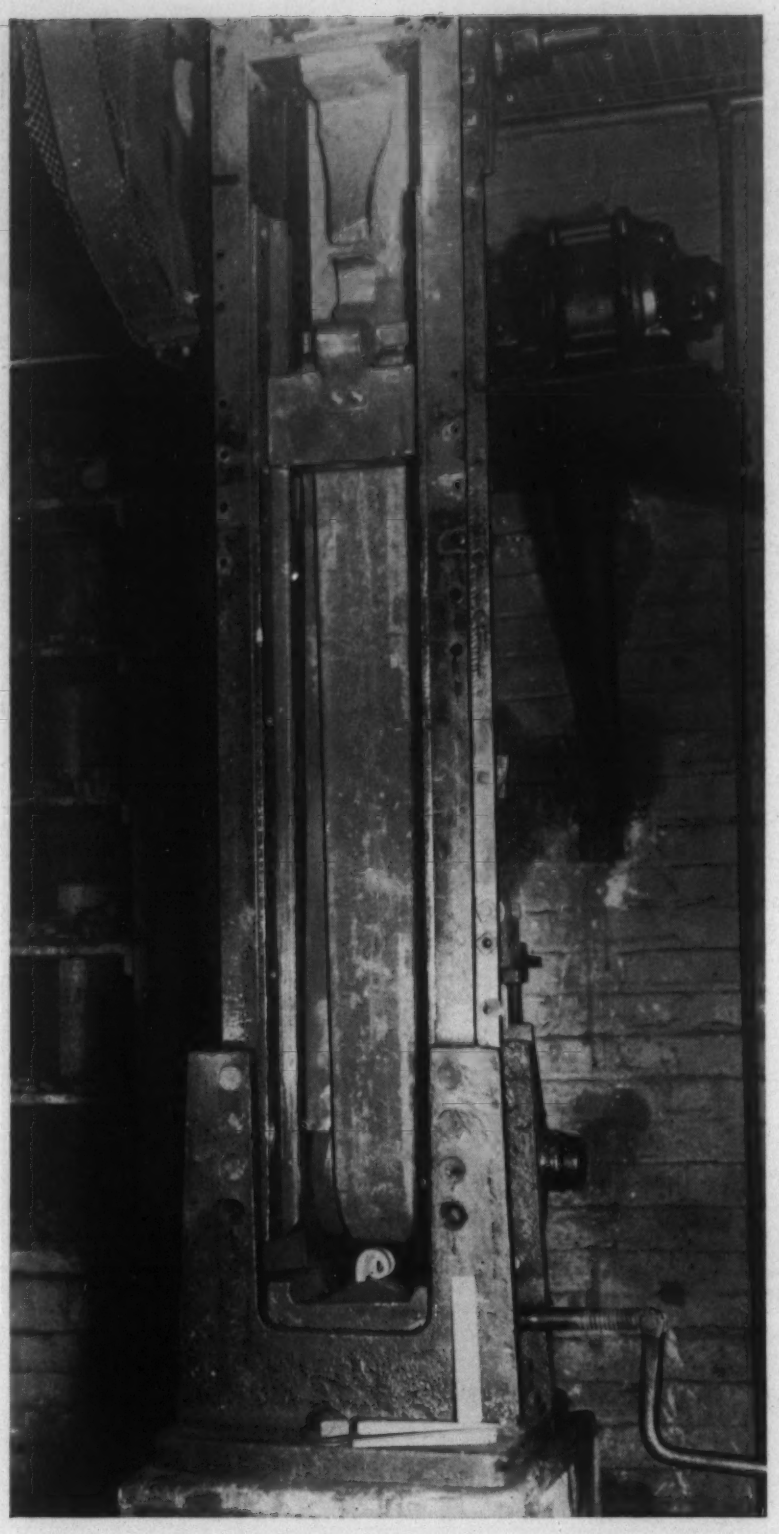
Spring hangers are produced in malleable to provide protection against occasional overloads. The ordinary load or regular stresses are chiefly borne by the main brace or bracket and the routine demands on the hanger are within the service capacity of less ductile materials. The shock incident to occasional overloads, however, increases the need and justifies the application of a tough metal.

This use directs attention to an unusual relation between the tensile strength and elongation of malleable iron which is almost unique among ferrous metals. In the case of most materials, the relation holds that tensile strength and elongation vary inversely, while for malleable iron the stronger product has the higher ductility. This leads to the interesting conclusion that both factors of energy of rupture and stress and strain work together, and the energy of rupture is not limited by a constantly falling elongation as the tensile strength is raised.

In considering another aspect of physical performance, the reduction of area in a malleable tensile specimen is not restricted to a short length of test. Each unit of reduced section is not appreciably weaker than the unstrained portion of the test length. It has been "toughened" by the "cold work" and tends to direct the next elongation to an adjacent spot. A continuation of this process spreads the elongation rather uniformly along the test length so that when final fracture occurs, there is no marked reduction of area at any point.

For uses such as the one in question, it appears advantageous to use a metal which is so toughened by cold working when loaded past its yield point rather than one which is drawn out. And observation of the behavior of malleable iron and other ferrous metals in the neighborhood of their yield points, when being subjected to tensile testing, indicates that small overloads should have relatively little harmful influence on the malleable material.

Outstanding uses among truck parts, particularly on the modern six-wheelers, are represented in the axle housings, spring chairs and perches, and radius rods. The spring



A Wedge Type Impact Testing Machine. The test wedge absorbs an impact of over 70 ft.-lbs. with each blow from the tup.

chair is a part which, fitted with a steel bushing, pivots on the cross shaft and carries the entire rear weight of the body, frame, and load. The radius rods absorb and transmit all thrust and torque loads from driving and braking, being subject to both shock and twist.

To the motorist, dependability of automotive parts is vividly demonstrated by the brake pedal, a part which must endure many sudden stresses. Accompanying illustrations exhibit a brake pedal as it is produced in the foundry and, in the same photo, a companion casting is shown distorted in the manner in which leverage is applied in practical use. It is obvious that at no time would the part be subjected to that kind of usage but this severe test does illustrate the fact that the casting can be deformed and bent almost into a straight line without fracturing. In the other view of companion pedals, one casting has been twisted into a corkscrew to demonstrate its ductility. It is this ductility which minimizes the hazard of sudden failure.

For Farm Implements

In the agricultural field, where implements suffer much abuse, malleable's use is stimulated by factors other than its impact resistance although this quality continues as the dominant consideration. Its relatively high corrosion resistance is an important characteristic when taking into account the influence of complex soil and atmospheric exposure to which farming implements are subjected. This quality may be viewed as its "weather durability," or another phase of the metal's all-purpose aspect.

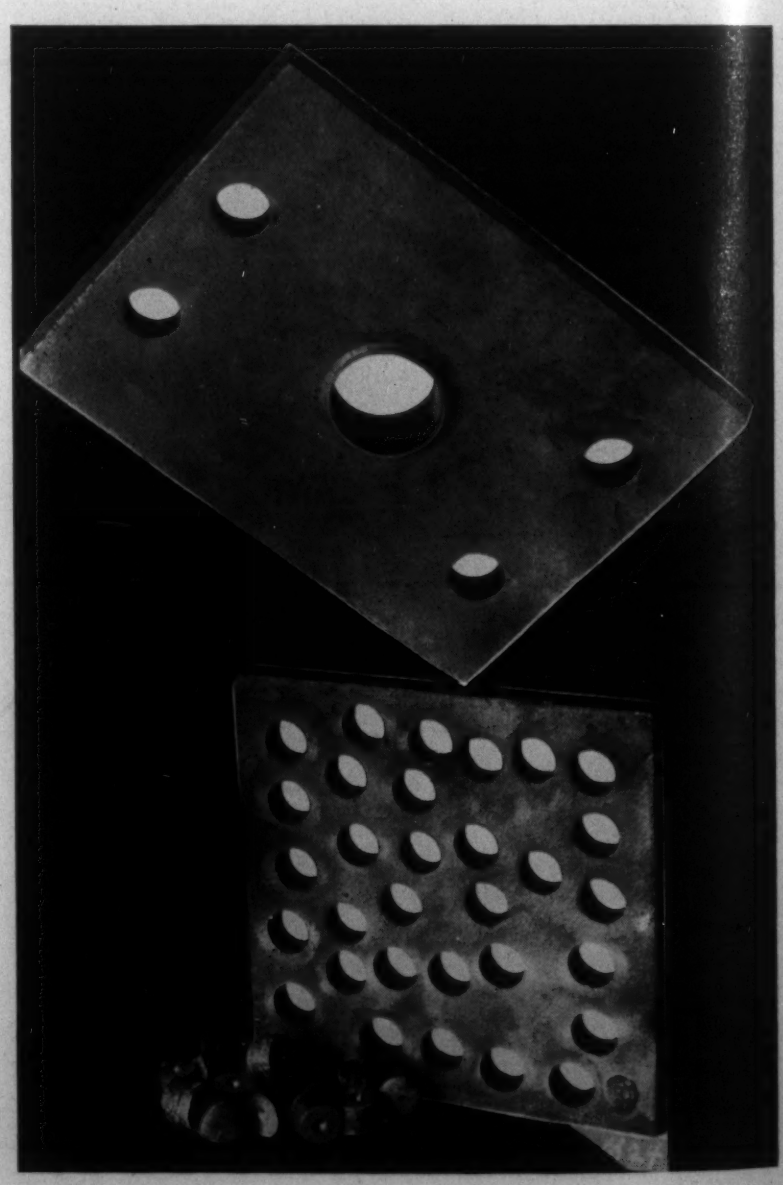
Freedom from assembly and elimination of machining operations are important essentials of economical participation in this field. It is necessary for foundrymen to demonstrate adaptability to unusual designs, and to assure the casting's trueness to pattern. An example of how design can be utilized to promote workability and easy maintenance is presented in the illustration of parts of a rotary hoe.

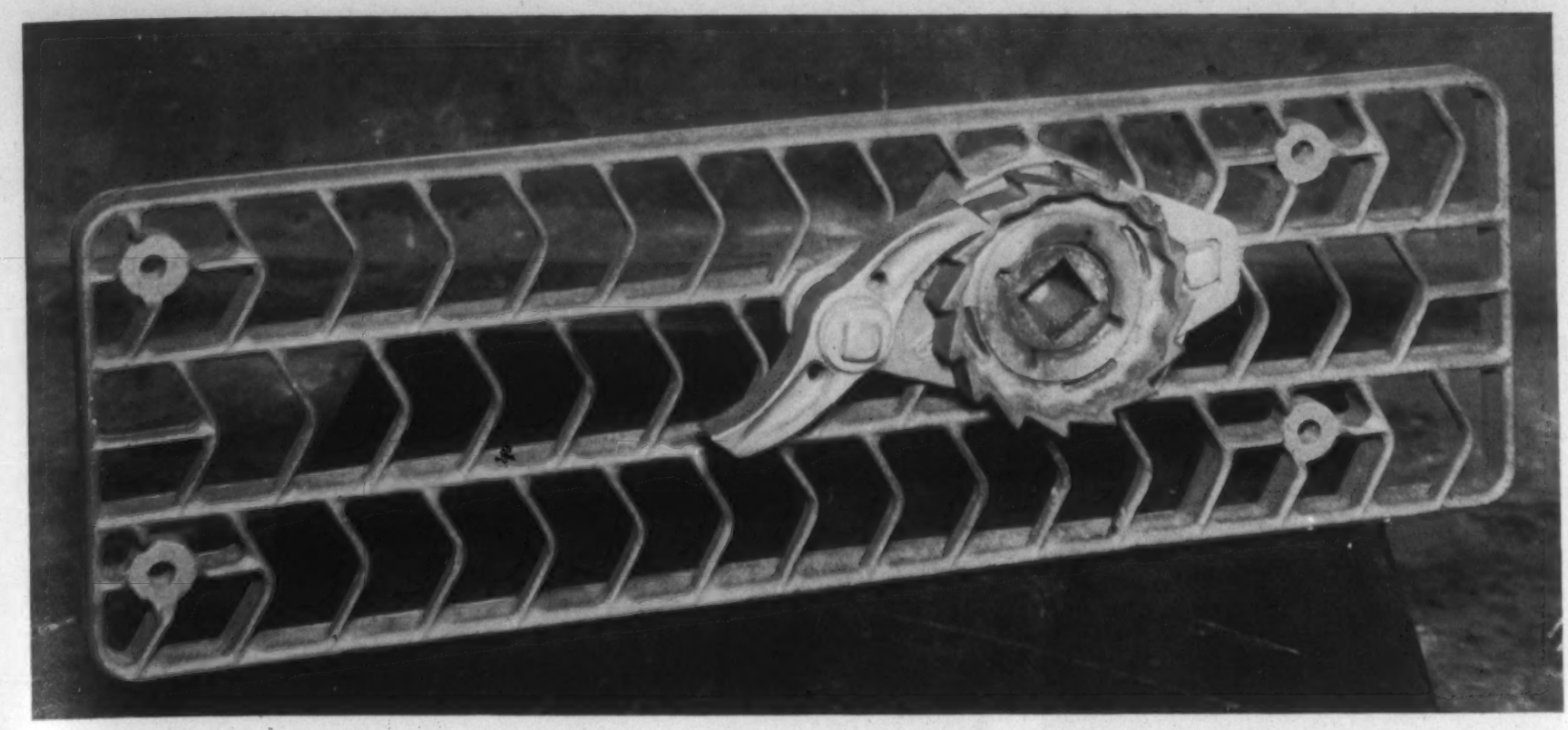
Other outstanding uses in this field are contained in tractor and bulldozer parts, in plows, harrows, pulverizers, diggers, cultivators and the like, as well as in miscellaneous tools and fittings.

For Railroad Equipment

In the railroad field, there is on the one hand, a desire for a low cost and strong material. Due attention is given

Drift Testing and Cold Punching. Malleable iron may eliminate the necessity for drilling because of its adaptability to cold punching. Note the proximity and clean cut appearance of the punched holes. The upper casting shows the degree of flaring possible; the central hole was expanded from a diameter equivalent to that of the other four holes.





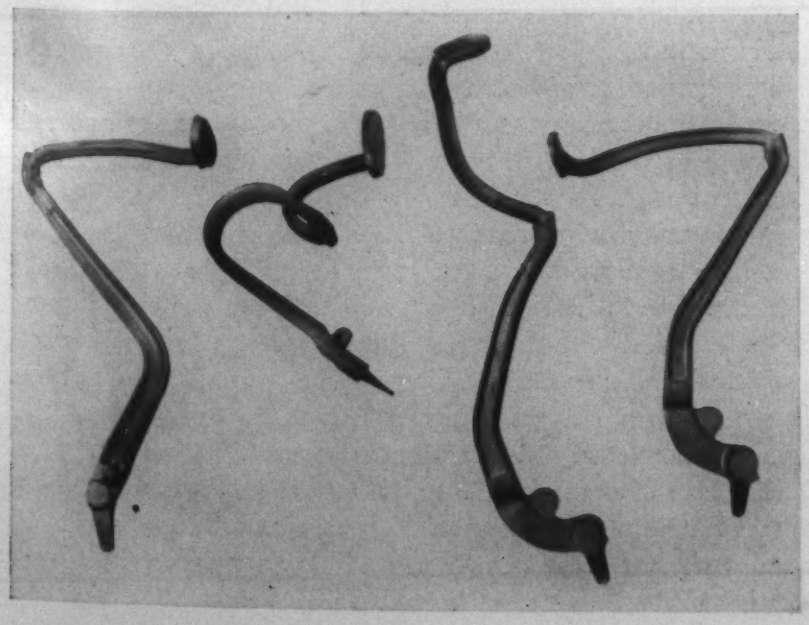
A Brake Step used on Freight Cars. The parts require rigidity, easy drainage, and high resistance to corrosion. The ratchet wheel, pawl, and pawl plate are also of malleable iron.

again, however, to shock and corrosion resistance. Items such as follower blocks and draft gear equipment represent severe uses from a shock standpoint as such parts absorb much of the impact occasioned by car coupling. Tests have shown malleable iron follower blocks withstanding 1000 blows under a drop hammer, force being transmitted by means of a standard coupler, without distortion of the key slot; the distortion of the block proper was only one-eighth of an inch.

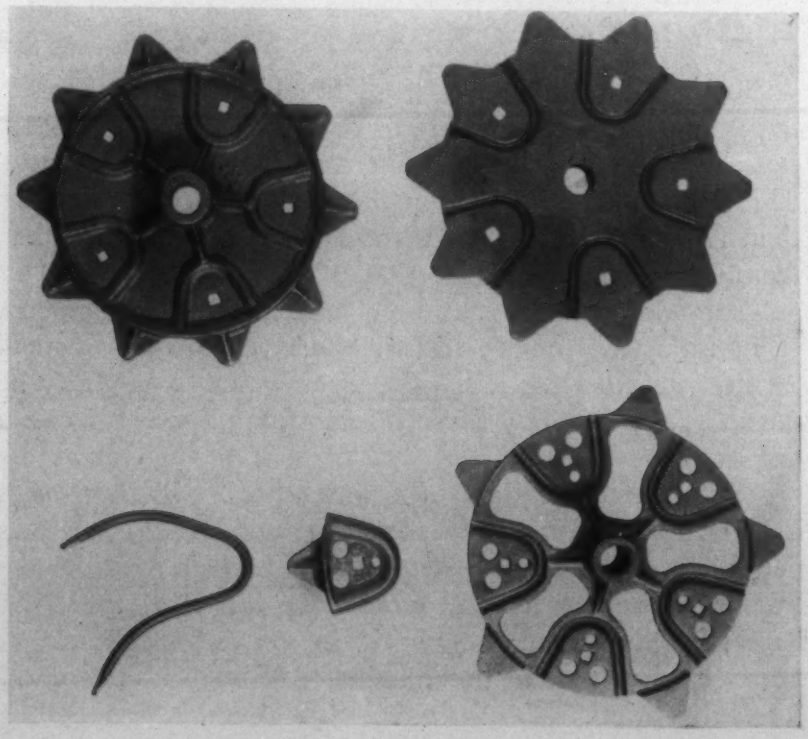
Railroad participation has been an important factor in stimulating the development of the currently high physical strength of malleable iron. In 1915, the standard specifications of the American Society for Testing Materials required a tensile strength of 38,000 lbs. per sq. in. and an elongation of 5 per cent for this material. Since that time, the specifications have been increased five times. Specification A-47-33 now lists two grades: Grade 32510 with a tensile strength of 50,000 lbs., a yield point of 32,500 lbs., and an elongation in 2 in. of 10 per cent; grade 35018 requiring a tensile strength of 53,000 lbs., a yield point of 35,000 lbs., and elongation of 18 per cent in 2 in.

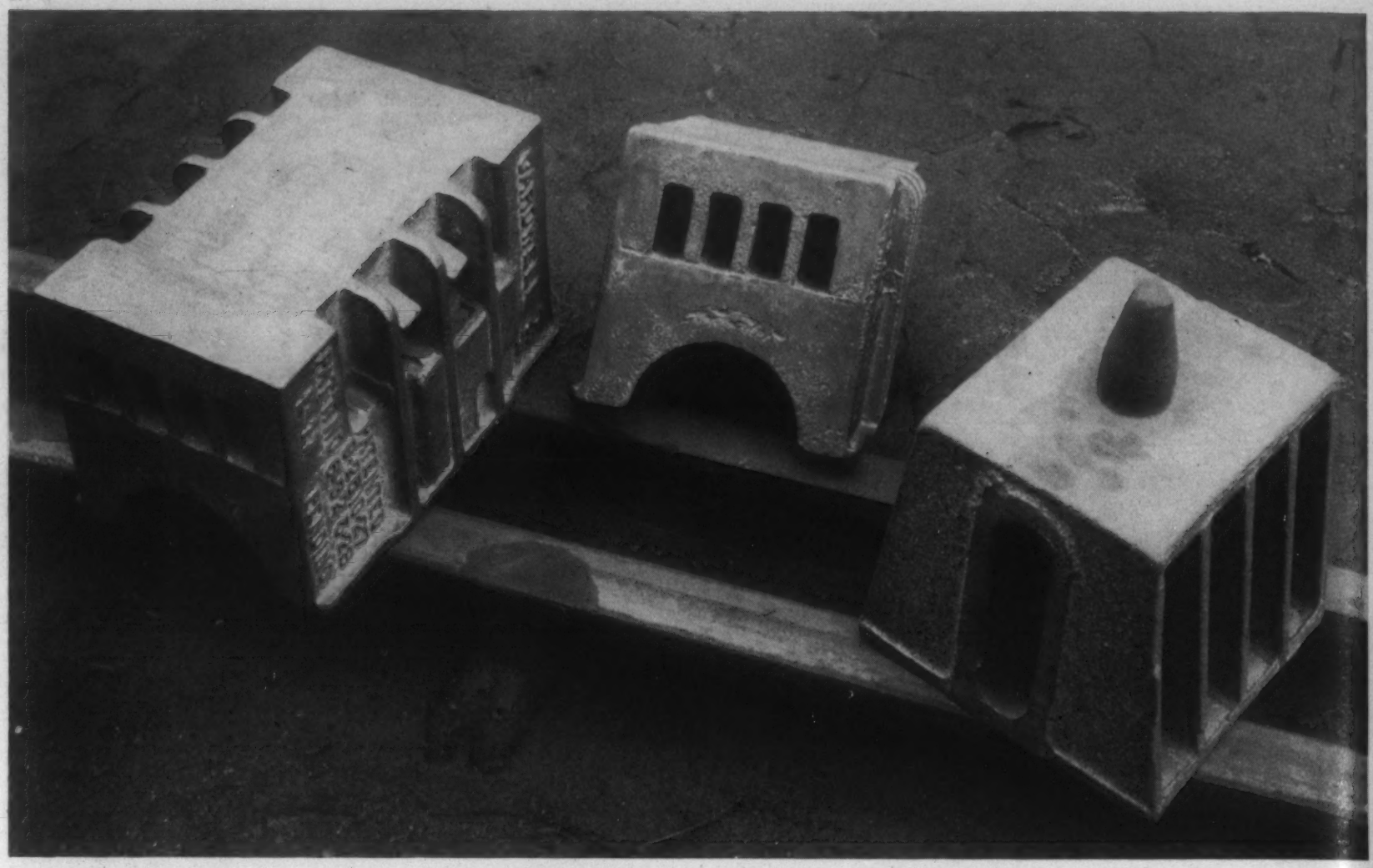
The latter grade is the one usually required for railroad

Brake Pedals of Malleable Iron as Produced and After Arbitrary Distortion. One of the pedals has been twisted into a corkscrew to show its ductility. The other has been deformed by applying exaggerated force in the manner in which leverage is applied in practical use—the casting has been bent almost into a straight line without fracturing.



Part of a Rotary Hoe, an Example of Workability and Latitude in Design in the Agricultural Field. Clamped in each of the five grooves on the spiders is a rolled spring steel "digger" (shown in the lower left). Twenty such units are mounted on a shaft in actual use. The part which wears out and requires frequent replacement is the digger. Removal of one digger, under the original design, required the dismantling of the machine and the removal of as many as 9 or 10 spider units. The malleable iron spider (lower right) reduced weight and permitted replacement by the removal of only one nut and bolt on the spider involved.





Outstanding Examples of Contributions of Malleable Iron in the Railroad Field are Follower Blocks, Striking Plates, Draft Lugs and Other Draft Gear Equipment. These represent severe uses from the standpoint of shock, since such parts absorb much of the impact presented by car coupling. These are modern types of follower blocks.

castings, and many foundries have concentrated on the production of even higher strength malleable. In this connection, a recent check on the uniformity and physical properties of the malleable product of a number of foundries revealed the following performance: Approximately 2700 tons of castings from 236 heats were involved. Tests from the 236 heats showed a maximum yield point of close to 40,000 lbs. per sq. in. and a minimum value of over 35,000 lbs. per sq. in., averaging almost 38,000 lbs. per sq. in. The elongation ranged from 18.5 to 31.0 per cent, averaging a shade over 23 per cent.

A High Yield Point

The indispensable properties that any member, subject to dynamic stresses or exposure to occasional overloads should possess, are a high yield point combined with toughness. This combination implies, in the case of the former, freedom from brittleness within the elastic range and freedom from brittleness after distortion.

The yield point of malleable iron is about 67 per cent of its ultimate strength, and this high relationship of yield to ultimate wins for it consideration which would not be possible where merely the ultimate strength was used as a criterion.

While the correct kind of an impact test will shed much light on the toughness of a metal, the notched bar test does not appear to be a satisfactory one in the case of malleable iron. An impact test encouraged by the Malleable Iron Research Institute, and now in use by some of the foundries, serves to demonstrate the toughness of malleable iron in forceful fashion.

Briefly, the test uses a tapered wedge 6 in. long and 1 in. wide, tapering in thickness from $\frac{1}{2}$ to 1/16 of an inch. The wedge is held upright on the anvil of a drop machine and is subjected to blows from a tup that weighs 21 lbs. and that drops from a height of 3.33 ft. The first blow represents the delivery of 70 ft.-lbs. of energy on a section that, due to the curling of the thin end, is somewhat larger than 1/16 sq. in.

The test is severe in that, due to the curl, the extreme fibers on the tension side are called upon to elongate greatly in a small fraction of a second. Under the test conditions, the upper end of the wedge will curl more and more under the successive blows of the tup, and the energy transmitted by the impact will increase somewhat due to the longer height of drop.

Thousands of such tests have shown that the product generally endures 20 to 30 blows, at which point the wedge is usually curled completely.

In torsion testing, test bars $\frac{3}{4}$ in. square at the end and 11 in. long, endure three or more complete revolutions, at usual lathe speeds, without sign of fracture.

Accompanying photographs illustrate these methods of testing, as well as the performance of malleable iron in cold punching and drifting operations. Cold punching must be regarded as a punishment that only the most "insensitive" and uniform metal will endure. The metal has been known to drift successfully as much as 150 per cent of the original diameter. Additional illustrations show castings before and after exposure to abnormal testing or attempts at destruction. These practical demonstrations serve to qualify the metal as a modern and serviceable working material.